TITLE 11
DEPARTMENT OF HEALTH
CHAPTER 23
UNDERGROUND INJECTION CONTROL

deposited over a formation or formations of volcanic origin. Caprock is substantially less permeable than volcanic formations, and is considered a "confining material".

"Confining materials or zone" means a geological formation or part of a formation capable of preventing or severely retarding fluid movement between different geological formations.

"Contaminant" means any substance or matter which causes, directly or indirectly, a detrimental physical, chemical, biological or radiological change in the existing water quality; used interchangeably with "pollutant".

"Department" means the department of health, state of Hawaii.

"Director" means the director of health or a duly authorized representative.

"Disposal well" means a well used for the disposal or emplacement of fluid or fluids, either by gravity flow or under pressure, into subsurface strata; often used interchangeably with "injection well".

"Exempted aquifer" means an aquifer or a portion thereof that is exempted from being used as an USDW by the director.

"Existing well" means a well which is in operation or has received official sanction from all of the necessary agencies, before the effective date of this chapter.

"Fluid" means any material or substance which flows or moves, whether a semisolid, liquid or gas.

"Formation" means a body of rock characterized by a degree of lithologic homogeneity or similarity which is prevailingly, but not necessarily, tabular and is mappable on the earth's surface or traceable in the subsurface.

"Geologist" means a person with a bachelors or higher degree in geologic sciences from an accredited college or university and a minimum of one year experience in well logging and testing.

"Ground water" means water below the land surface in a zone of saturation.

"Grouting" means the operation whereby a cement slurry is forced behind the casing for such purposes as: sealing the casing to the walls of the hole, preventing undesirable leakage of fluids out of the hole, and preventing migration of liquids or gases into the hole; or is pumped into a drill hole or well for plugging and abandonment.

"Hazardous waste" means a hazardous waste as defined extensively in Code of Federal Regulations potability, mineral content, turbidity, color or odor of USDW are adversely affected; or

(B) To discharge any liquid, gaseous, solid, radioactive, or other substances, into any state waters as will or is likely to create a nuisance or render such waters unreasonably harmful, detrimental or injurious to public health, safety or welfare, including harm, detriment, or injury to public or private drinking water supplies.

"Sewage" means waste from all plumbing fixtures in residences, institutions, public and private buildings, and other places of human habitation, employment or recreation, whether treated or not by public or private sewage treatment plants.

"State" means state of Hawaii.

"UIC" means the underground injection control program under Part C of the Safe Drinking Water Act (P.L. 93-523) and chapter 340E, HRS.

"UIC Line" or "the Line" means the line on the department of health UIC maps which separates, in plan view, exempted aquifers and USDW.

"Underground source of drinking water (USDW)" means an aquifer or its portion:

(1) Which supplies any public or private drinking water system; or contains a sufficient quantity of ground water to supply a public water system; and
   (A) Currently supplies drinking water for human consumption; or
   (B) Contains fewer than ten thousand milligrams per liter (mg/L) total dissolved solids (TDS); and

(2) Which is not an exempted aquifer.

"Volcanic" means material originating from a volcano; often, basaltic lava.

"Waste" means any solid, liquid or gaseous matter, whether treated or not, which, when injected, may pollute or tend to pollute the lands or waters, including, but not limited to, sewage; effluent; offal; garbage; refuse; and industrial, agricultural or radioactive fluids.

"Waste disposal system" means an excavation in the ground receiving wastes which functions by allowing fluids to seep through its bottom, sides or both, including cesspools, septic tanks, and seepage pits.

"Well" means a bored, drilled or driven shaft, or a dug hole, whose depth is greater than its widest surface dimension.

§11-23-05 <u>Identification of exempted aquifers and USDW</u>. (a) The department has designated the following formations as exempted portions of aquifers: in the horizontal dimension, lands which are makai of the UIC Line; and in the vertical dimension:

(1) Where the volcanic formation is a non-artesian aquifer, the entire geologic column; or
(2) Where the volcanic formation is an artesian aquifer, from the subaerial ground surface down to fifty feet above the contact between the artesian volcanic aquifer and the overlying confining materials.

(b) Unless an aquifer is expressly exempted, as described above or depicted on the department-issued UIC maps, it is an underground source of drinking water.

(c) In areas where the UIC Line is defined by a roadway, a setback of one lot or one hundred fifty feet, whichever is less, from the mauka property line of that roadway may be considered to be within the exempted area. If the roadway is within a property, the setback shall extend to the mauka property line or to one hundred fifty feet from the mauka edge of said roadway, whichever is less. This interpretation of the UIC line shall be subject to all other conditions of this chapter. The applicant, on the permit application, shall request this interpretation, approval of which shall be based on the proximity and sensitivity of drinking water sources. [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.7 and 146.4)

§11-23-06 <u>Classification of injection wells</u>. (a) The department shall classify existing and proposed injection wells in accordance with the five classes of wells described in this section. Wells in classes I through IV are prohibited and are defined as follows:

(1) Class I. Wells which inject fluids beneath the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water and which are used by:
    (A) Generators of hazardous waste or owners or operators of hazardous waste management facilities; and
    (B) Disposers of industrial and municipal waste fluids.

formation, including non-exempted aquifers (USDW). Subclass B wells include:

(A) Air conditioning return flow wells used to return the water used for heating or cooling in a heat pump;

(B) Cooling water return flow wells used to inject water previously used for cooling;

(C) Drainage wells used to inject (often by gravity flow) surface fluids, primarily storm runoff;

(D) Recharge wells used to replenish, augment, or store water in an aquifer;

(E) Salt water intrusion barrier wells, used to prevent the intrusion of salt water into fresh water, if they inject water of equal or lesser chloride concentration as that portion of the aquifer into which injected;

(F) Wells used in aquaculture, if the water in the receiving formation has, either:

- (i) An equal or greater chloride concentration as that of the injected fluid; or
- (ii) A total dissolved solids concentration in excess of five thousand mg/L.

(G) Injection wells used in an experimental technology, which is one that has not been proven feasible under the conditions in which it is being tested; and

(H) All wells not included in subclasses A or AB of class V or in classes I through IV. [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.6 and 146.5)

§11-23-07 Prohibition. (a) Without exception, any injection wells not defined by class V in section 11-23-06 shall not be permitted to be constructed, operated or to exist in the state. Class V injection wells shall be permitted to be constructed, modified and operated to the extent provided by, and subject to, the requirements of this chapter.

(b) No new subclass A or AB well shall be constructed or operated in a non-exempted aquifer after the effective date of this chapter.
[Eff. JUL 6, 1984] (Auth: HRS §340E-2)
(Imp: HRS §340E-2, 40 CFR §§144.11, 144.12, 144.24 and 146.52)

subsection (a), the department of health shall require the applicant to submit water quality data representative of local conditions as part of the application. Where water quality data is lacking or insufficient to determine the areal water quality, the department may require the applicant to collect representative water samples from the injection well during construction. The samples shall be collected and analyzed, in accordance with standards and methods established in chapter 11-20, entitled "Potable Water Systems". The parameters for which values shall be identified are, at least, the following:

(1) Chloride concentration,

(2) Total dissolved solids (TDS), and

(3) Coliform - Total; if found, then fecal and streptococcus determinations.

(d) The variety of injection wells and their uses dictate a variety of construction designs consistent with those uses, and precludes specific construction standards for each type of injection well outlined in this chapter. However, an injection well shall be designed for its intended use, in accordance with good engineering practices as recommended by the Honolulu Board of Water Supply's "Water System Standards", dated March, 1977.

(e) Vertical migration resulting in undesirable mixing of fluids from aquifers of substantially different water quality (due to improper well construction or use of an injection well) shall be prevented by preserving the integrity of the confining zone or zones by grouting or some other method acceptable to the department.

(f) If a large void, such as a lava tube or solution cavity, is encountered during drilling, where the drill rod drops more than three feet, measures shall be taken to prevent unacceptable migration of the injected fluids. The owner shall either verify that the void does not slope inland or construct the well in such a manner that wastes are not injected directly into the void. For the first option, a test boring which verifies the void's inclination inland of the wellsite shall be drilled. For the second option, the section of the well casing which passes through the void shall be without openings. Either the perforated casing shall be replaced with solid casing, or the holes in the casing shall be sealed by grouting or in some other manner approved by the department. The owner shall notify the department to arrange discussion and approval of any corrective actions. Scheduling of the procedures shall be arranged so that the from logs of borings in the vicinity. If, however, artesian aquifer conditions are encountered, the applicant shall have the options as set forth in subsection (f). The following is a table showing the depths needed to achieve the 1:2 ratio:

Proposed depth of injection well:	10	15	20	25	30	40	50	60	70	80	90	100
Minimum depth of caprock:	70	80	90	100	110	130	150	170	190	210	230	250

(d) If the ratio of the depth of the proposed injection well, to the estimated depth of caprock less fifty feet, is greater than 1:2, the applicant shall have the depth of the injection well temporarily extended by fifty feet to verify that artesian aquifer conditions are not encountered within that range. The fifty feet of extended hole shall be properly sealed by the tremie method, with a cement slurry that contains no more than five gallons of water per ninety-four pound sack of cement.

(e) Where a test well is planned for either a single injection well or a multiple well field, the depth of the test well shall be extended fifty feet into confining materials beyond the proposed depth of the deepest well. If the test well is intended to be operational, the lower fifty feet shall be properly sealed as detailed in subsection (d).

(f) Where artesian aquifer conditions are unexpectedly encountered, the applicant may choose to:

(1) Abandon and properly seal the injection well with neat cement and request approval for a new location; or

(2) Modify the depth of the injection well or wells so that it conforms with subsection (a)(1). [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.11 and 144.12)

§11-23-11 <u>Operating conditions</u>. (a) No injection well shall be operated, modified or otherwise utilized without a UIC permit issued by the department.

(b) No person shall construct, operate, maintain, convert, plug, abandon or conduct any other injection activity in a manner which allows the movement of fluid containing a contaminant into underground sources of drinking water, if the presence of that contaminant may

(2) Are operated by the same person;
(3) Are similarly designed;
(4) Serve the same purpose; and
(5) Inject into the same aquifer or injection zone at the same property.

(d) All applications shall be submitted with a filing fee of $100 for each application. Any government agency shall be exempt from paying this filing fee. Additionally, when public notice is required, as provided in section 11-23-14, the applicant shall pay all fees assessed for publishing legal notice or notices for each application requiring public notice. If a public hearing is required, as provided in section 11-23-15, the applicant shall pay all fees assessed for publishing legal notice or notices for each application requiring such notice.

(e) The department shall not consider any incomplete application. An application is deemed complete when:
(1) All requested information has been submitted, including the application form, plans, maps and other exhibits;
(2) All fees have been paid; and
(3) All public notice and hearing requirements under sections 11-23-14 and 11-23-15 have been satisfied. [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §§144.24 and 144.33)

§11-23-13 Submission of data. (a) Each applicant shall provide the following:
(1) Facility name;
(2) Facility location, including street address and zipcode;
(3) Tax map key (TMK) number and map at the most detailed scale available, showing proposed injection well or wells location on the property, the correct scale and north arrow;
(4) USGS topographic quadrangle map or good copy (scale 1:24,000) indicating the location of the proposed injection well or wells, and all other injection and withdrawal wells within one-quarter mile of the facility boundary;
(5) Ownership of facility;
(6) Name and address of lessor, if applicant is a lessee, and written consent of the property owner;
(7) Name and address of legal contact;
(8) Name of proposed operator;

authorization to operate shall be issued until the information is provided. [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §§340E-2 and 340E-9, 40 CFR §§144.25, 144.26 and 144.33)

§11-23-14 <u>Public notice of proposed wells injecting into USDW</u>. (a) The director shall notify the public of every application for a well proposing to inject into an underground source of drinking water in a manner designed to inform interested and potentially interested persons. Public notice procedures shall include at least the following:

(1) Notice shall be circulated within the geographical area in which the proposed injection is located. The circulation shall, at the discretion of the director, include either or both of the following:
  (A) Posting in the post office and public places of the municipality nearest the premises of the applicant in which the injection well facility is located; and
  (B) Publishing in local newspapers and periodicals or in a daily newspaper of general circulation.

(2) Notice shall be mailed to any person or group upon request; and

(3) The director shall add to a mailing list the name of any person or group who requests copies of notices for all UIC applications which propose the use of a USDW for injection purposes within the State or a certain geographical area.

(b) The director shall provide a period of not less than thirty days following the date of the public notice, during which time interested persons may submit their written views with respect to the UIC application. All written comments submitted during the thirty-day comment period shall be retained by the director and considered in the formulation of the final determination with respect to the UIC application. The period for comment may be extended at the discretion of the director.

(c) The public notice shall include at least the following:

(1) Name, address and phone number of the agency issuing the public notice;

(2) Name and address of each applicant;

(3) Brief description of each applicant's activities or operations which intend to

(d) The public notice of any hearing held pursuant to this section shall include at least the following information:

(1) Name, address and phone number of agency holding the public hearing;
(2) Name and address of each UIC applicant whose application will be considered at the hearing;
(3) Name of USDW area where injection is proposed and a short description of the underground source of drinking water aquifer;
(4) A brief reference to the public notice issued for each UIC application being considered, including identification number and date of issuance;
(5) Information regarding the time and location of the hearing;
(6) The purpose of the hearing;
(7) A concise statement of the issues raised by the persons requesting the hearing;
(8) Address and phone number of the state agency premises at which interested persons may obtain further information, and inspect and copy UIC forms and related documents; and
(9) A brief description of the nature of the hearing, including the rules and procedures to be followed. [Eff. JUL 6, 1984] (Auth: HRS §340E-2) (Imp: HRS §340E-2, 40 CFR §145.31)

§11-23-16 Permit issuance. (a) The director shall issue a UIC permit for wells which propose to inject into exempted aquifers on the following basis:

(1) Existing or new injection wells do not or will not endanger the quality of underground sources of drinking water.
(2) Existing or new injection wells are designed and are or will be constructed or modified to operate without causing a violation of these rules or other applicable laws.
(3) Proposed injection wells are designed and built in compliance with the standards and limitations stated in sections 11-23-07 to 11-23-10.

(b) The issuance of a UIC permit for wells which propose to inject into USDW shall be based, in addition to subsection (a)(1) to (3), upon the evaluation of the contamination potential of the local water quality by the injection fluids and the water development

(f) Existing wells of any subclass, which are determined to be polluting underground sources of drinking water shall have one year from the time of determination to effect corrective actions. If the pollution is not abated, the permit shall not be renewed or shall be suspended or revoked.
[Eff. JUL 6, 1984] (Auth: HRS §340E-2)
(Imp: HRS §340E-2, 40 CFR §§144.15, 144.26, 144.31, 144.33 and 146.52)

§11-23-18 <u>Monitoring and reporting requirements</u>.
(a) The operator of any injection well or wells shall keep detailed records of the operation of the well or wells, including, but not limited to, the type and quantity of injected fluids, and the method and rate of injection for each well.

(b) If the operation of the injection well or wells is additionally regulated by other pollution control programs, e.g., National Pollution Discharge Elimination System (NPDES), the adherence to their monitoring and reporting requirements shall be considered a requirement of this chapter.

(c) The owner of any injection well or wells shall within one month report any change in ownership to the director in writing. Until such time as the notice of change in ownership is submitted, the registered owner shall be responsible for the operation of the well or wells and for damages resulting from improper operation of the well or wells.
[Eff. JUL 6, 1984] (Auth: HRS §340E-2)
(Imp: HRS §340E-2, 40 CFR §§144.51 and 144.54)

§11-23-19 <u>Plugging and abandonment requirements</u>.
(a) Any owner who wishes to abandon an injection well shall submit an application, in accordance with section 11-23-12, containing the details of the proposed abandonment. The department may require an abandoned well to be plugged in a manner which will not allow detrimental movement of fluids between formations. If required, plugging shall be completed by grouting with the tremie method in accordance with the Honolulu Board of Water Supply's "Water System Standards", dated March, 1977; or by some other method found appropriate and acceptable to the department.

(b) The department may order an injection well to be plugged and abandoned when it no longer performs its intended purpose, or when it is determined to be a threat to the ground water resource. The owner shall

[Eff. JUL 6, 1984] (Auth: HRS §340E-7) (Imp: HRS §340E-8, 40 CFR §§144.11 and 145.13)

§11-23-22 Severability. If any provision of this chapter or its application to any person or circumstances is held invalid, the application of such provision to other persons or circumstances, and the remainder of this chapter, shall not be affected thereby. [Eff. JUL 6, 1984] (Auth: HRS §340E-9) (Imp: HRS §340E-9)

The Department of Health authorized the adoption of Chapter 23 of Title 11, Administrative Rules on Underground Injection Control following public hearing held on Lanai on November 7, 1983, on Molokai on November 8, 1983, on Maui on November 9, 1983, on Hawaii on November 14, 1983 in Hilo and on November 15, 1983 in Kona, on Oahu on November 16, 1983, on Kauai on November 17, 1983, after public notice was given in the Maui News on September 21, 1983, in the Hawaii Tribune-Herald on September 21, 1983, in West Hawaii Today on September 22, 1983, in the Honolulu Advertiser on September 22, 1983, and in the Garden Isle on September 21, 1983.

Chapter 23 of Title 11, Administrative Rules shall take effect ten days after filing with the Office of the Lieutenant Governor.

Charles G. Clark

CHARLES G. CLARK
DIRECTOR
DEPARTMENT OF HEALTH

APPROVED:

George R. Ariyoshi

GEORGE R. ARIYOSHI
GOVERNOR
STATE OF HAWAII

Date: 6-25-84

APPROVED AS TO FORM:

DEPUTY ATTORNEY GENERAL

Filed: JUN 26 1984

Effective Date: JUL 6 1984

REC'D BY
1984 JUN 26 AM 10 45
LT. GOVERNOR'S OFFICE

'A GEOTHERMAL VENTURE
.awaii Partnership

April 10, 1992

John C. Lewin, M.D.
Director
Department of Health
P.O. Box 3378
Honolulu, HI 96801

SUBJ: UNDERGROUND INJECTION CONTROL (UIC)
UIC APPLICATION NO. UH-1529

Dear Dr. Lewin:

Pursuant to the Department of Health (DOH) letter of March 16, 1990, to Puna Geothermal Venture (PGV) which outlined the requirements necessary for issuance of an Underground Injection Control (UIC) Permit to Operate (UIC Application No. UH-1529), PGV respectfully submits the following:

For Well Kapoho State 1A (KS-1A)

1) Engineering/Geologic Re
2) Casing Monitoring Progr

PGV.

The Hydrologic Monitoring Program for K
of 1990.

KS-1A & KS-3

For Well Kapoho State 3 (KS-3

UIC Permit Application

1) Casing Inspection and In

4-10-92

Items previously submitted for KS-3 wer
Program (April, 1990), a Casing Monitor
1991) and an Engineering/Geologic Report

Based on these submittals, Puna Geothe
requests that we be issued an Undergrounc
(UIC Application No. UH-1529) and Perm. . .... injection
Wells Kapoho State 1A (KS-1A) and Kapoho State 3 (KS-3).

14-3860 Kapoho Pahoa Road, Pahoa, Hawaii 96778 • (808) 961-2786 • Facsimile (808) 935-5562
Post Office Box 1337, Hilo, Hawaii 96721-1337

If you have questions or require additional information, please contact me.

Sincerely,

Thomas G. Kizis

Thomas G. Kizis
Environmental Manager

TK/vla

cc: W. Paty, DLNR
C. Hew, DOH
M. Tagamori, DLNR
J. Swift, DLNR
J. Florez, DLNR
E. Tanaka, DLNR
R. Nakano, HCPD
S. Morris, PGV
D. Berube, PGV
B. Rickard, PGV
J. Sternfeld, PGV

Memo No: B21202
Files: KS-1A, KS-3, UIC

PRODUCTION AND INJECTION WELL CASING MONITORING PROGRAM

1. INTRODUCTION

1.1 Background

Pursuant to Underground Injection Control (UIC) Permit No. UH-1529, the Hawaii State Department of Health (DOH) requires Puna Geothermal Venture (PGV) to develop a Casing Monitoring Program (CMP) regarding production and injection wells. This program is to be submitted to and approved by DOH prior to start of operation of injection wells drilled under permit UH-1529, for the PGV project site.

1.2 Purpose

The purpose of this CMP is to specify the observations, tests, drilling operations and, if necessary, remedial actions required to insure that the mechanical integrity of production and injection casing and cement is maintained throughout the drilling, testing and operation of PGV wells. The cemented and hung casing strings that are used in the PGV wells are designed to prevent contamination of any underground sources of drinking water (USDW) by either reservoir fluid in production wells or power plant effluent in injection wells. Contamination of the USDW's might occur if the casing strings are breached due to corrosion or mechanical failure or if there is a failure of the cement to seal the casing/borehole annulus above the zone of injection or production. The casing monitoring program described below is designed to detect and diagnose a loss of mechanical integrity in the casing or cement. Remedial actions required to restore mechanical integrity are also described.

1.3 Scope

This CMP covers all production and injection wells drilled by PGV and all existing wells that were drilled by previous operators on the 500 acre PGV site which to date have not been plugged and abandoned.

1.4 Hydrogeologic Basis for the Casing Monitoring Program

The hydrogeologic basis for the CMP is derived from data available from the drilling of five production wells to depths ranging from 6500' to 8000' and by two shallow monitoring wells drilled to depths of 640' and 720' (Figure 1).

1.4.1. The shallowest zone extending from surface (approximately 620' above sea level) to about 7' above mean sea level is unsaturated and consists of a highly permeable sequence of subareal basalt flows and interflow breccias. Within the project area this zone varies in thickness from 600' to 720' depending on the surface elevation. Numerous cracks with widths of up to 2' traverse the area. These cracks are vertical or very steeply dipping and reach from the surface to at least the top of the warm unconfined aquifer described below. This is evidenced by the discharge of warm moist air from many of these cracks. The cracks trend parallel to the major structures and lineaments of the Lower East Rift Zone.

1.4.2 The zone below the unsaturated surface rock consists of an unconfined aquifer which contains ground water with varying degrees of natural contamination from the underlying geothermal system. This zone is approximately 1400' thick with the water surface elevation controlled by sea level according to the Ghyben-Herzberg model. The unconfined aquifer surface in the project area is approximately 7' above mean sea level. Based on the model, the thickness of the low salinity lens is therefore about 280'. This constitutes the USDW. The salinity of the underlying water will probably approach that of sea water. The temperature of the unconfined aquifer zone ranges from 95° to 192° F. in the project area and tends to be nearly isothermal throughout the entire interval, indicating good vertical mixing. A detailed description of this aquifer is given in the Puna Geothermal Venture Hydrologic Monitoring Program submitted to DOH in April 1990.

1.4.3. The interval from 1400' below sea level to 2400' below sea level (2000' to 3000' GL in Figure 2) is characterized by an extremely steep thermal gradient in the range of 30 F/100' or more. The steep temperature gradient is characteristic of conductive heat transfer and indicates the zone has essentially zero vertical permeability. Thus, the zone appears to be an effective aquitard separating the high temperature geothermal fluid below from the low temperature unconfined aquifer overlying it. Locally the aquitard exhibits natural leakage as in the area of MW-2 and GTW-III where anomalously high shallow ground water temperatures and salinities are observed.

1.4.4 Between the depths 2400' and 4300' below sea level (3000' to4900' GL in Figure 2) the temperature profile indicates the existence of a transition zone which consists of alternating permeable and impermeable strata. Within this zone are two or more alternating zones of high thermal gradients and isothermal intervals. The high average thermal gradient through this zone indicates that vertical fluid circulation is very limited.

1.4.5 Below a depth of about 4300' below sea level (4900' GL in Figure 2) the temperature profile becomes nearly isothermal. This interval is within the geothermal reservoir in which significant vertical movement of fluid is taking place at temperatures above 620 degrees F.

The casing program planned for the production and injection wells calls for cemented casing to reach from ground surface to a depth of about 3400' below sea level (Figures 3 and 4). This allows the casing to be anchored securely within the transition zone described in 1.4.4 and to fully isolate the geothermal reservoir from the shallow aquifer (lowermost USDW) with a cemented interval through the aquitard (1400'-2400' below sea level). Within the shallow aquifer zone, two cemented casing strings are installed. Three cemented casing strings pass through the top of the shallow aquifer and the unsaturated zone. The production and injection casing programs are designed to prevent leakage of geothermal fluid from the wellbore into the shallow aquifer above a depth of 1400' below sea level. The CMP discussed below provides the methods and procedures necessary to detect any leakage and to repair those leaks if detected.

2. PRODUCTION WELL CASING MONITORING PROGRAM

2.1 Pressure Testing During Drilling

Each production well is completed with three casing strings (not including the 30-inch conductor pipe) cemented to the surface (Figure 3). Immediately upon completion of cementing each casing string and prior to drilling out the cement shoe, the casing will be pressure tested. The test will consist of pressurizing the casing to a specified test pressure and holding for 30 minutes. The specified test pressure shall be the lesser of: (a) 2000 psig surface pressure or (b) 70% of the casing internal yield pressure less 250 psi at the shoe. (2000 psig is the maximum expected surface pressure on the 9-5/8" casing during production operations.) The pressure change during the 30 minute period shall not exceed 8%. The effect of the fluid expansion due to thermal recovery in the wellbore during the test period will be negligible throughout the test period.

In the event that excessive bleed-off occurs, one or more of the following diagnostic methods will be used to locate the leak:

- Temperature log while injecting
- Static temperature survey

- Casing inspection logs with multi-arm caliper and/or magnetic inspection tools
- Pressure testing with a packer(s) on drillpipe
- Other applicable methods

After identification of the point of leakage, a cement squeeze job will be performed and the casing retested. Results of each pressure test will be reported to the Department of Land and Natural Resources (DLNR) and the Department of Health (DOH),

After a successful pressure test of each casing string, drilling will proceed to a point at least one foot below the cement shoe, and a pressure leak-off test will be performed to test the integrity of the annular cement. Each test will be performed at a pressure approaching the fracturing pressure of the exposed formation. If there is excessive leak-off, a squeeze cement job will be performed, the cement will be drilled out and the test will be repeated. Drilling will not proceed until an effective cement seal is established in the casing/borehole annulus above the shoe. In some situations, such as the case where there is natural formation permeability immediately below the casing shoe, it may not be practical to prove cement integrity with the pressure test described above. As an alternative, a standard water shutoff test (WSO) may be done above the shoe, or shut-in temperature surveys may be run.

If there have been indications of problems with the 9-5/8" cement job, a cement bond log (CBL) will be run in the 9-5/8" casing. Adequate cement curing time will be allowed before running the CBL.

Although CBL's may be of interest on the surface and intermediate casing strings, they are not planned because the necessary logging tools are not available from PGV's logging contractor to obtain meaningful results in the large diameter, 20" and 13-3/8" casing strings. CBL's are not commonly run in geothermal production and injection wells on the mainland, and they are virtually never run on the surface and intermediate casings. The large surface and intermediate casing sizes common to geothermal wells cannot be bond logged with useful results using conventional logging tools.

With regard to the surface and intermediate casing strings, if any problems are suspected from the results of the cement job or pressure testing, a static temperature survey will be run to check for interformational flows behind the casing. The shut-in time before logging will be sufficient to obtain useful results.

If the CBL is run in the 9-5/8" production casing it will be used only to determine cement tops or as a diagnostic tool. The logging results will not meet oil and gas standards for cement bond or cement compressive strength. This is due to two factors:

2.1.1 Because of the temperature limitations on logging tools, a well must be cooled by water injection during the logging operation. The resulting thermal contraction of the casing creates a temporary micro annulus between the casing and cement. Therefore, the log shows that no bond exists. This micro annulus is believed to seal after the well heats back up to the usual temperature. The micro annulus is usually so small that it would only be a problem with high pressure gas and would not provide a flow path for geothermal fluids.

2.1.2 The cement used in geothermal wells is relatively light weight, low compressive strength cement. Geothermal casing is usually cemented in place over its entire length and the cement used must be lightweight or the formation will fracture due to the hydrostatic pressure from the cement column. Fracturing and the resultant loss of circulation cause an incomplete primary cement job. Any secondary cementing procedure usually never approaches the quality of a successful primary cement job. All of the light weight cements available on the market produce relatively low compressive strengths when set. High compressive strengths are not required for geothermal wells because the casing is cemented over its entire length. This supports and protects the casing and seals off any possible flow in the annulus. This is unlike the common practice in oil and gas wells where casing is cemented only to seal off the zones of interest or fresh water zones. The main method of determining the competency of the casing cement job while drilling will be the surface indications of pressure and circulation returns during the cement job and the shoe leak-off test. If both of these are positive, the cement job has an extremely high probability of providing a good seal against the migration of production fluids.

2.2 Monitoring During Injection Testing

Upon completion of each production well an injection test may be performed to give an initial indication of reservoir permeability. The injection test consists of pumping relatively cool, fresh water into the wellbore at several controlled rates while monitoring downhole and wellhead pressure. Temperature-pressure-spinner (TPS) logs will normally be run during the test. These logs can be used to locate leaks in the casing by noting a sudden change in temperature with depth or a drop in flow velocity within the casing string. In the event that a loss of mechanical integrity is indicated during or after injection, one or more of the following diagnostic methods will be used to confirm the leak:

- Temperature log while injecting
- Static temperature survey
- Casing inspection logs with multi-arm caliper and/or magnetic inspection tools
- Other applicable methods as determined by PGV.

2.3 Monitoring During Flow Testing

During flow testing of each production well, wellhead temperature and pressure along with steam and brine flow rate and chemistry are continuously monitored. After the initial 24 hours of flow, flow characteristics tend to be stable. Sudden changes in the wellhead pressure, temperature, brine/steam ratio, or brine chemistry during stabilized flow can be indicative of a loss of mechanical integrity which is allowing cool water leakage into the wellbore.

Also during flow testing, TPS logs are periodically run. Leakage of cool water into the wellbore or loss of fluid to zones behind casing may be seen in the TPS logs run during or after shut-in. In the event that wellhead or logging data indicate a loss of mechanical integrity during the flow test, the well will be shut in and one or more of the following diagnostic methods will be used to confirm the leaks and locate it more precisely:

- Temperature log while injecting
- Static temperature survey
- Casing inspection logs with multi-arm caliper and/or magnetic inspection tools
- Other applicable methods as determined by PGV

2.4 Monitoring During Production

Wellhead pressure and temperature will be monitored daily during normal production. Brine and steam chemistry will also be analyzed for each production well. Initially, samples will be taken weekly to establish a baseline geothermal fluid chemistry. The sampling frequency will then be reduced to monthly and quarterly as stabilization of the fluid chemistry is confirmed.

Casing failure causing leakage of cool ground water into the wellbore or loss of geothermal fluid to the formation may be manifested as a pressure and temperature drop at the wellhead. Fluid chemistry changes may also indicate ground water leakage. Wellhead pressure, temperature, and chemistry data will be reported to the DOH quarterly on a routine basis.

In the event that anomalous production parameters are observed, TPS survey(s) will be run with the well flowing. The TPS profiles will be used to determine whether the observed changes are due to changes in reservoir characteristics or are caused by a loss of mechanical integrity. In the event of a suspected loss of mechanical integrity, one or more of the following diagnostic methods will be used to confirm the leak and locate it more precisely:

- Temperature log while injecting
- Static temperature survey
- Casing inspection logs with multi-arm caliper and/or magnetic inspection tools
- Other applicable methods as determined by PGV

2.5 Casing Repair

Once a loss of mechanical integrity is identified and approximately located, casing repair procedures will be initiated. These procedures may include any or all of the following activities:

2.5.1 Shut in well and run magnetic and multi-arm casing inspection logging tools to precisely locate leak and to evaluate casing condition.

2.5.2 Rig up workover rig on well. Run packer(s) on drillpipe and pressure test to confirm suspected leaking interval.

2.5.3 Execute cement squeeze job to seal casing leak or stop interformational flows behind casing.

2.5.4 Perform casing pressure test and other diagnostic tests as necessary to confirm success of the remedial work. If good, move rig off well and return well to production.

2.5.5 In the event of major casing failure, a cemented liner may be installed through the damaged interval.

2.5.6 Prior to drilling out the liner shoe, the liner will be pressure tested as described in Section 2.1.

2.5.7 If mechanical integrity cannot be restored satisfactorily, the well will be plugged and abandoned.

3. INJECTION WELL CASING MONITORING PROGRAM

3.1 Pressure Testing During Drilling

The cemented casing string design in PGV injection wells (Figure 4) is similar to that of production wells. Testing of each string will proceed as described in 2.1 above.

3.2 Monitoring During Injection Testing

Prior to installation of the hangdown liner, an injection test will be performed to measure injectivity of the open formation below the cemented 9-5/8" casing. During the test, one or more of the following logs or surveys will be run:

- TPS through the open hole and cased intervals with the well on injection.
- Static temperature surveys to check for evidence of interformational flows behind casing.
- Other logs or surveys, as determined by PGV, to check for mechanical integrity of the casing and cement.

If the results of the logs and surveys confirm mechanical integrity, then the 7" hangdown liner may be installed. If leakage is found, repair procedures as described in 2.5 will be performed.

3.3 Monitoring During Routine Injection

During routine injection, the 7" x 9-5/8" annulus will be purged with nitrogen. Purge pressure and flow rate will be monitored for any changes indicative of a casing leak. Purge will be repeated as necessary to maintain the fluid level more than 1/2 way down the annulus. Once annually, tests and surveys will be conducted to verify mechanical integrity of the hangdown liner. The casing and hangdown liner will be tested for leaks by one of the following procedures, or a combination thereof:

3.3.1 Perform a pump-down test on the 7" x 9-5/8" annulus. Nitrogen will be injected into the annulus to a pressure sufficient to displace the water level to the 9-5/8" casing shoe and shut in. Surface pressure on the annulus and hangdown liner will be monitored and recorded. Annulus pressure bleed-off exceeding 8% in 30 minutes will be considered indicative of a leak. If necessary, the pressure test will be extended beyond 30 minutes to preclude thermal effects on the surface pressure. In that case, the final 30 minutes will constitute the test period.

<u>or</u>

3.3.2 If the hangdown liner is pulled, the casing may be pressure tested above a bridge plug or packer set near the shoe following the basic procedure outlined in Section 2.1. Integrity of the hangdown liner may be verified by inspection on the surface, by a pressure test after it is run in the hole, or by a TPS log with the well on injection.

Integrity of the cement will be checked during each workover by one or more of the following procedures:

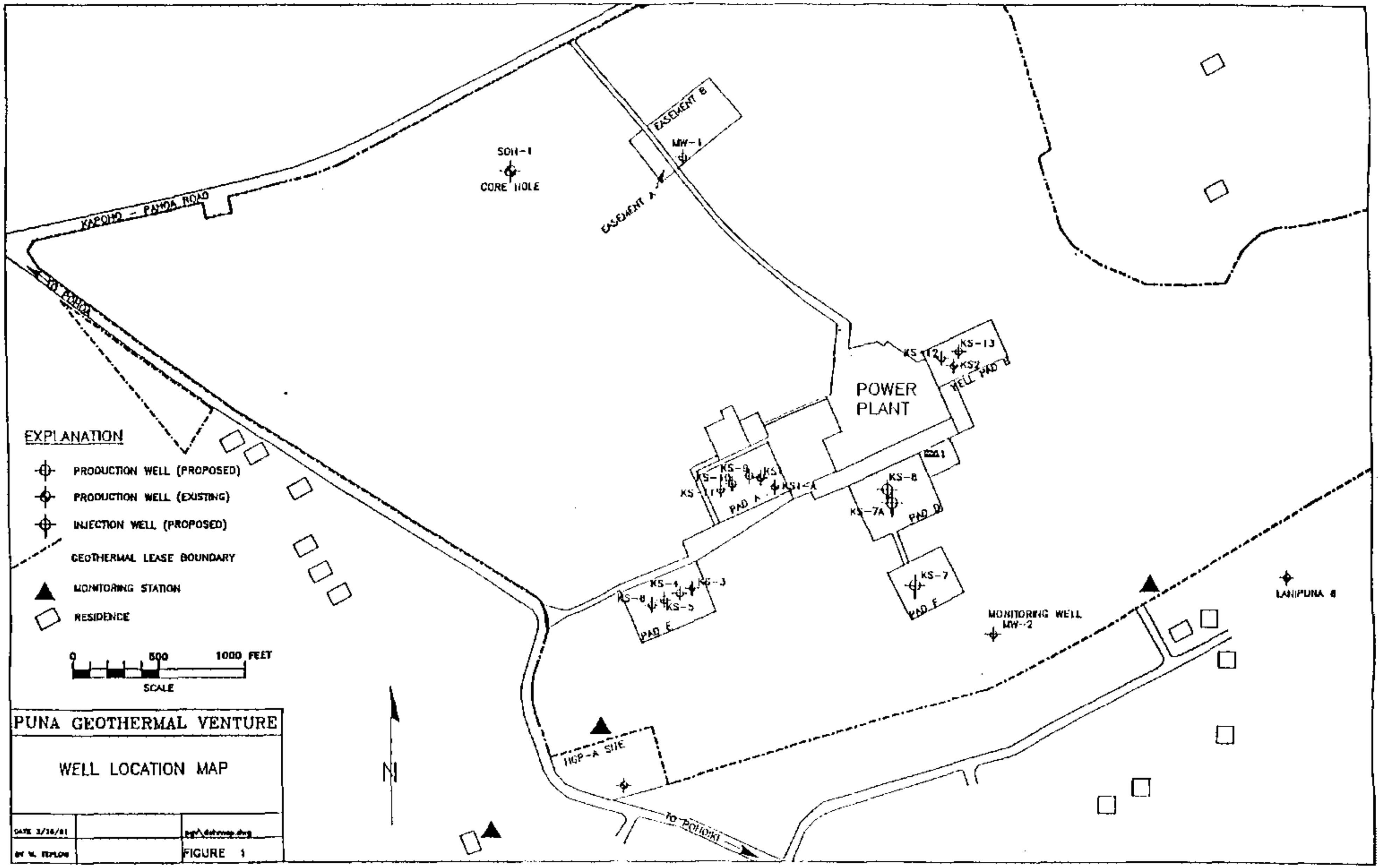
3.3.3 One or more shut-in static temperature surveys will be run. Shut-in time will be at least 12 hours, or longer if necessary to obtain meaningful results.

<u>or</u>

3.3.4 Other logs or surveys may be run, at the discretion of PGV, if static temperature surveys are not definitive.

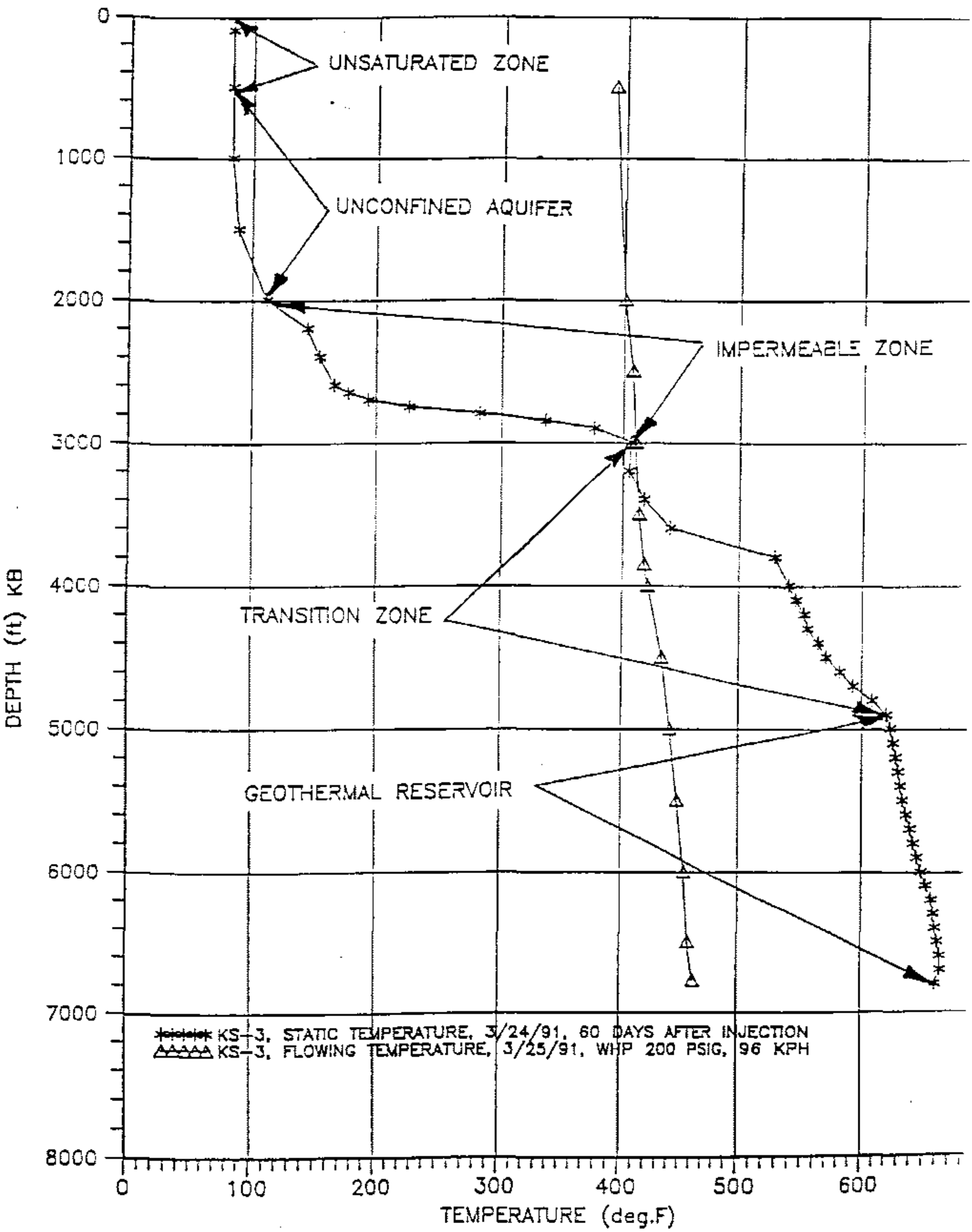
3.4 Restoration of Mechanical Integrity or Abandonment

In the event that the diagnostic procedures indicate a loss of mechanical integrity, remedial or abandonment procedures will be carried out as specified in Section 2.5.

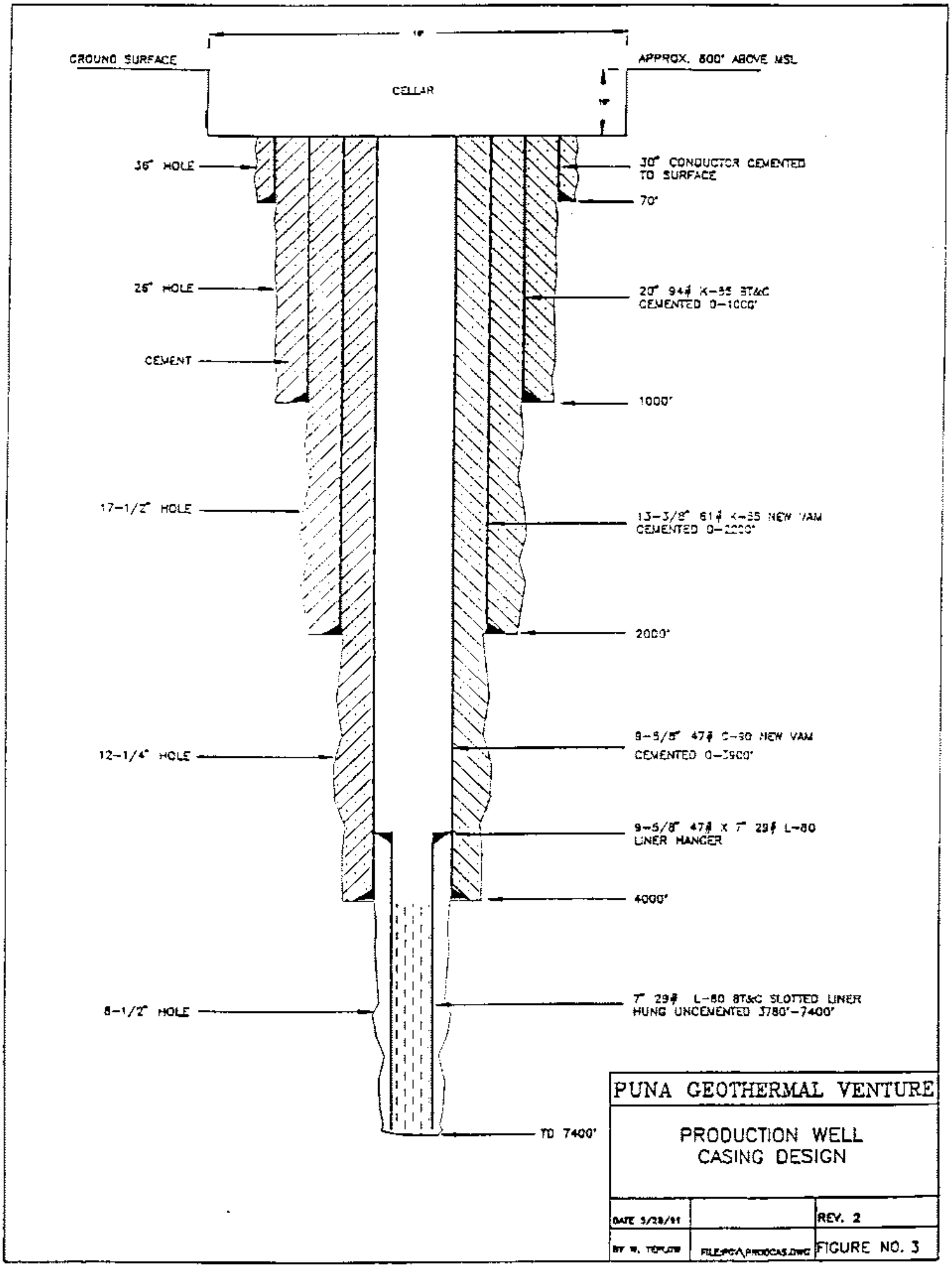


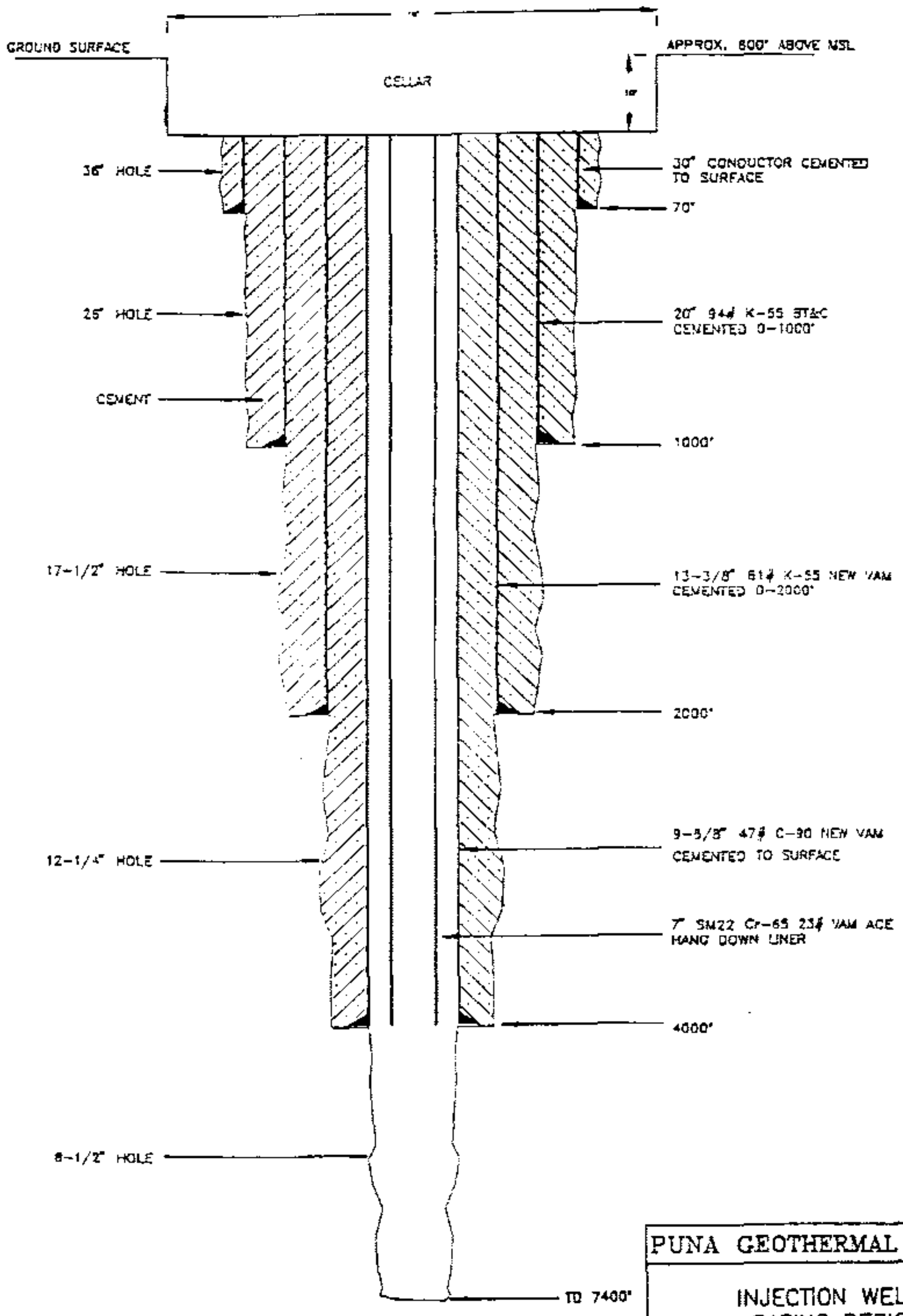
KAPOHO - PAHOA ROAD
TO PAHOA
SOH-1
CORE HOLE
EASEMENT B
MW-1
EASEMENT A
POWER PLANT
KS-13
WELL PAD B
KS-8
KS-7A
PAD D
PAD A
KS-1A
KS-4
KS-3
KS-5
PAD E
KS-7
PAD F
MONITORING WELL
MW-2
LANIPUNA 6
HGP-A SITE
TO POHOIKI
N
EXPLANATION
PRODUCTION WELL (PROPOSED)
PRODUCTION WELL (EXISTING)
INJECTION WELL (PROPOSED)
GEOTHERMAL LEASE BOUNDARY
MONITORING STATION
RESIDENCE
0
500
1000 FEET
SCALE
PUNA GEOTHERMAL VENTURE
WELL LOCATION MAP
FIGURE 1

PUNA GEOTHERMAL VENTURE
KS-3 STATIC AND FLOWING
TEMPERATURE PROFILES



FIGURE


GROUND SURFACE
APPROX. 600' ABOVE MSL
CELLAR
36" HOLE
30" CONDUCTOR CEMENTED TO SURFACE
70'
26" HOLE
20" 94# K-55 ST&C CEMENTED 0-1000'
CEMENT
1000'
17-1/2" HOLE
13-3/8" 61# K-55 NEW VAM CEMENTED 0-2000'
2000'
12-1/4" HOLE
9-5/8" 47# C-90 NEW VAM
CEMENTED 0-3900'
9-5/8" 47# X 7" 29# L-80 LINER HANGER
4000'
8-1/2" HOLE
7" 29# L-80 BT&C SLOTTED LINER HUNG UNCEMENTED 3780'-7400'
TO 7400'
PUNA GEOTHERMAL VENTURE
PRODUCTION WELL
CASING DESIGN
REV. 2
FIGURE NO. 3



PUNA GEOTHERMAL VENTURE		
INJECTION WELL CASING DESIGN		
DATE 4/1/91	File	REV. 1
BY W. TEPLOW		FIGURE NO. 4

ENGINEERING AND GEOLOGIC REPORT FOR INJECTION WELL KAPOHO STATE 1A

1. General Information
   a. Well Designation: Kapoho State 1A
      Location: TMK 1-4-01:02, Kapoho, Puna, Hawaii
      (see Figure 1)
      Leased to: Kapoho Land Partnership
      Subleased to: Puna Geothermal Venture
      Operator: AMOR VIII Corporation

   b. Well Kapoho State 1A, located on Pad A (see Figure 2), was drilled in 1985, the third geothermal well drilled by Thermal Power Corporation. The well was worked over and the casing modified by Puna Geothermal Venture in 1991. The locations of other existing wells and planned wells are shown on Figure 3. Elevation of the wellhead is 618 ft above sea level.

2. Physical Characteristics of the Area
   a. The Puna Geothermal Venture Project is a 500-acre lease located in the Puna District of the County of Hawaii, approximately 21 miles southeast of the city of Hilo, in the Kapoho section of the Kilauea Lower East Rift Geothermal Resource subzone (see Figure 4).

   b. The project area lies on the windward side of the Big Island of Hawaii and receives 100 to 150 inches of rain per year. Daytime winds are generally Trades blowing from the northeast, at 10 - 30 miles per hour, and nighttime winds blow from the northwest at slightly diminished speeds.

   c. The wellfield and power plant are located on the southern flank of Puu Honuaula, a cinder cone with an elevation of 860 ft. The topography to the south-southeast of the puu has a moderate slope of approximately 10° (15 ft/100 ft) with some minor undulations. The wellfield to the southwest of the puu is generally flat with an average elevation of about 610 ft.

   d. Pad A was constructed on basalt flows from the 1955 eruption. The original surface was grubbed and a platform of compacted fill, consisting of rock and cinder was constructed.

   e. Earthquake and volcanic hazard risks are high in the East Rift Zone. Seismic and volcanic risk assessment reports were prepared for the project. Power plant structures conform with Seismic Zone 4 requirements and the brine injection pipelines were designed with expansion loops which will minimize the effects of fissuring, subsidence and ground swelling. The cellar of KS-1A was specially designed to be readily filled with volcanic cinders in order to reduce the chances of structural failure in the event of a lava flow.

f. Flood problems are not anticipated in the project area due to the highly porous nature of the surface basalt flows.

g. For information confirming conformance with local land use planning and zoning regulations, see Appendix I.

3. Description of System Operation

a. All geothermal fluids produced during operation of the PRG Project wellfield and power plant, including geothermal brine, geothermal steam condensate and geothermal noncondensible gases, will be injected back into the geothermal reservoir. Geothermal reservoir fluids will be produced typically from depths greater than 4000 ft and reinjected at equivalent depths.

The fluid from the production wells will be sent through a separator which will separate the steam from the residual brine. The brine will be directed to the injection facility and the steam will be directed towards the power plant. Within the environs of the power plant, the steam will pass through steam turbines and then low pressure OEC vaporizers. The by-products of the power generation system are steam condensate and noncondensible gases. These three components, the separated brine, steam condensate and noncondensible gases, will be recombined prior to injection in order to produce a fluid with the same composition as the original geothermal fluid.

Table 1 shows the anticipated range of geothermal brine and steam condensate chemistries as described in the Puna Geothermal Venture GRP application. Table 2 compares brine analyses from KS-1A and KS-3 with shallow ground water analyses from nearby PGV monitor wells and Puna District water supply wells (Pahoa and Kapoho/Green Lake).

The anticipated range of noncondensible gas chemistries, modified from the PGV GRP application is presented in

Table 3; Representative noncondensible gas analyses from KS-3 and KS-1A have been added.

b. The 25 MW Net power plant is designed to run on approximately 505,000 lb/hr of steam derived from an original geothermal fluid that will separate into 35% to 60% steam and 65% to 40% brine. Anticipated mass flow rates of injectate are as follows:

	Estimated normal rates based on 60% flash (lb/hr)	Estimated maximum rates (lb/hr)
Condensate	505,816	505,816
Brine	337,211	939,373
Supplemental water and/or brine from storage pits	0	144,516
Total NCG	1,573	2,696
Total Flow	844,600	1,592,404

c. The injection system (see Figure 5) consists of four components: (1) a brine accumulator and brine injection pump; (2) a noncondensible gas compressor, noncondensible gas system condensate pump and a noncondensible gas injection pump; (3) a condensate accumulator, condensate pump, and condensate injection pump; and (4) a water injection pump, necessary to maintain fluid volume if any OEC's are taken off-line. Each component of the system will be backed by spare fluid pumps. A spare noncondensible gas compressor and a spare geothermal injection well will also be provided.

In the event of an upset in the injection system, the injectate will be discharged into an unlined holding pond at the power plant site constructed to receive and temporarily store the geothermal brine and/or condensate. Prior to discharge into the holding pond, the brine will pass through an emergency steam release facility.

The steam release facility will consist of two rock mufflers. Each rock muffler is designed to dissipate the steam's acoustic energy, thereby reducing the noise associated with steam release. Each muffler is designed to handle 570,000 lb/hr of steam, which is 100% of the maximum total plant steam flow. Prior to entering the

the H_2S entrained in the steam. Removal of 96% of the H_2S is anticipated from the caustic treatment system.

d. Three injection wells are planned to serve four to five production wells. KS-1A and KS-3 have been designated as injection wells.

Estimated normal and maximum injection rates for the project are given in Section 3b.

f. The injection well will be utilized 24 hours per day.

g. No treatment of the steam or brine is planned under normal power plant operating conditions.

4. Geohydrologic Considerations

a. KS-1A is located on Pad A. Wellhead coordinates are 19°28.79' North Latitude and 154°53.60' West Longitude. Ground elevation is 618 ft above sea level.

b. The lithology of KS-1A is summarized in Table 4. The formation consists wholly of tholeiitic basalts and differentiated tholeiitic basalts deposited as extrusive flows which have been cross cut by differentiated tholeiitic intrusive dikes. The extrusive basalts can be subdivided into three units based on recognizable textural characteristics induced by their depositional environment. These units are subaerial aa and pahoehoe flows, submarine pillow basalts and a transitional unit consisting of hyaloclastites intercalated with subordinate volumes of pillow basalts and subaerial flows. The frequency of intrusive dikes increases with depth. Dikes are extremely rare in the upper 2000 ft of KS-1A but are the dominant rock type below 5140 ft.

The 9⅝-in. casing shoe was set at 4061 ft KB and demarcates the open hole interval. As noted in Figure 6, the rig KB reference is 18 ft above ground level. The formation encountered in the open section of the hole consists of two rock types, pillow basalts and intrusive dikes. From drilling rates and examination of the core from SOH 1, the dikes are basically unaltered and non-fractured and behave as localized aquitards. The pillow basalts are in part brecciated. Pillow breccias display varying degrees of hydrothermal alteration and vug mineralization.

The static water table was encountered at approximately 603 ft KB.

c. A chemical analysis of the groundwater collected while drilling is unavailable. A chemical analysis of groundwater sampled from monitor well MW-2, located 1500 ft southeast of KS-1a, is found in Table 2 .

d. Thermal Power Corporation conducted an injection test of KS-1A in December of 1985 in order to quantitatively evaluate the formation permeability below the shoe at 4061 ft. The results of the test indicated an injectivity index of 2.2 gpm/psi. Pressure fall-off data were inconclusive.

Casing inspection surveys and a 12-hour injection test were conducted by Puna Geothermal Venture between March 14 and 20, 1992 in preparation for converting KS-1A to an injection well. The results of this test program are attached as Appendix II. The pertinent data are summarized below.

At the end of the injection test the well was taking 451 gpm at a wellhead pressure of 208 psi (see Figure 3 of Appendix II). The associated injectivity index was calculated at 0.8 gpm/psi. Based on the expected chemical characteristics of the power plant injection fluids, fluid temperatures of 200°F and an applied wellhead pressure of 150 psi, the calculated injection capacity of KS-1A is 400 gpm.

Review of the temperature-pressure-spinner survey run during the flow test (see Table 2 of Appendix II and the static pressure-temperature survey run one day after injection (see Figure 7 of Appendix II) indicates that essentially all the water is exiting the wellbore below 4600 ft.

Calculated flow capacity of KS-1A, based on a Horner plot of the fall-off data (see Figure 5 of Appendix II), is 14,800 md-ft/cp.

e. KS-3 is also an injection well.

f. The casing schematic and descriptions of materials are attached as Figure 6. A fish, consisting of approximately 311 ft of drillpipe, drill collars and a mill was left in the hole between 5745 ft and 6056 ft.

William J. Teplow   4/7/92

William Teplow, Geologist   Date

REGISTERED GEOLOGIST
WILLIAM J. TEPLOW
No. 4521
STATE OF CALIFORNIA

Robert V. Verity   April 7, 1992

Robert Verity, Petroleum Engineer   Date

REGISTERED PROFESSIONAL ENGINEER
ROBERT V. VERITY
NO.
P 001606
exp. 9/30/95
PETROLEUM
STATE OF CALIFORNIA

APPROVED F

CONSTRUCTI

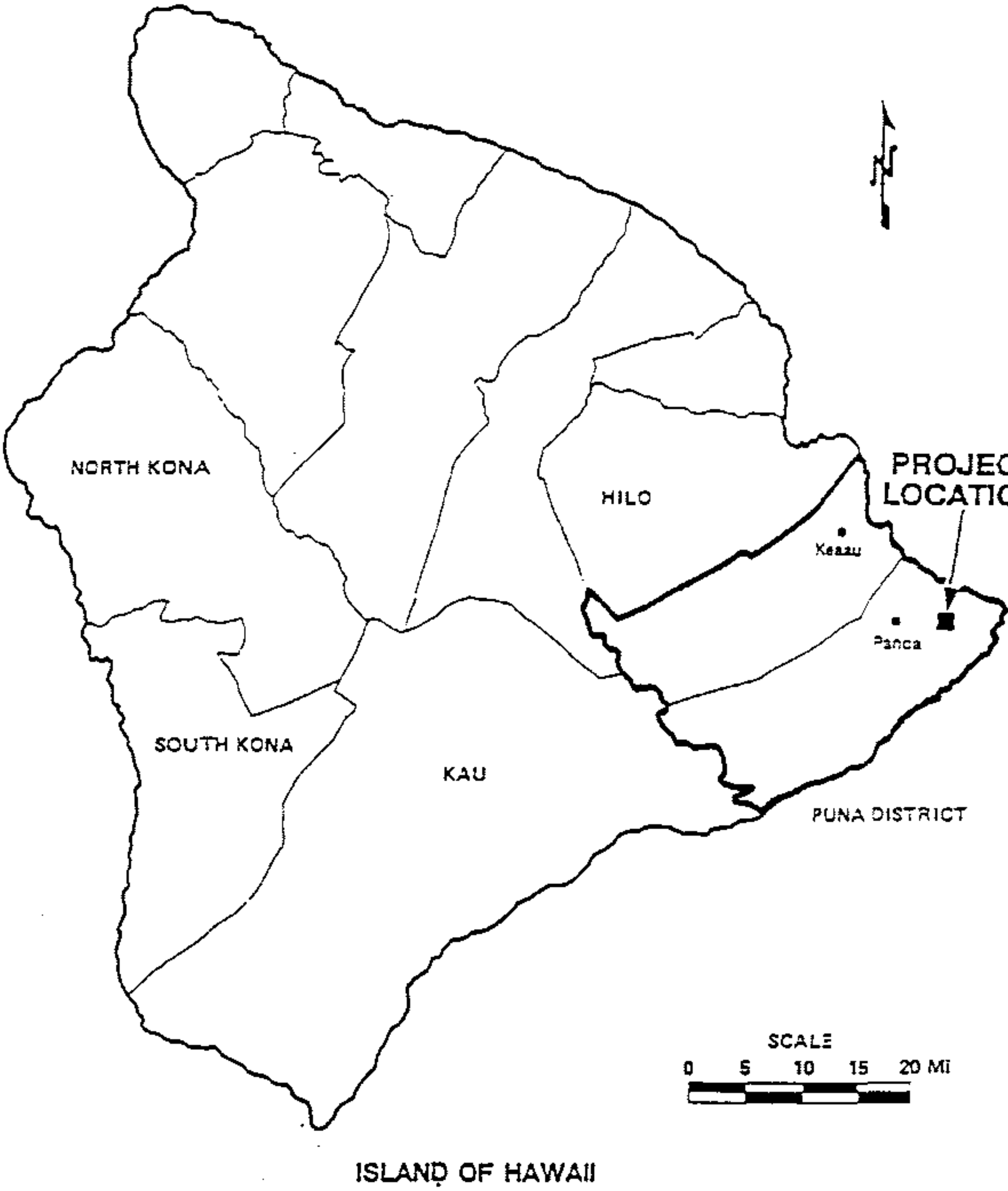
DATE:

REVISION: 1

BY: a.n.

REVISION	SHEET NO.	DRAWING NO.		
1	C-19	89041	PUNA GEOTHERMAL VENTURE 25 M.W. POWER PLANT GRADING PLAN ~ WELLPAD "A"	Okahara Associate CONSULTING EN 200 KOHOLA STREET HILO, HAWAII 96720 TEL: (808) 961-5527 470 N HONC

FIGURE 4



SOURCE: State of Hawaii, Department of Planning and Economic Development. STATISTICAL BOUNDARIES A-15. 1980:14

Location of the Puna District

FIGURE 6

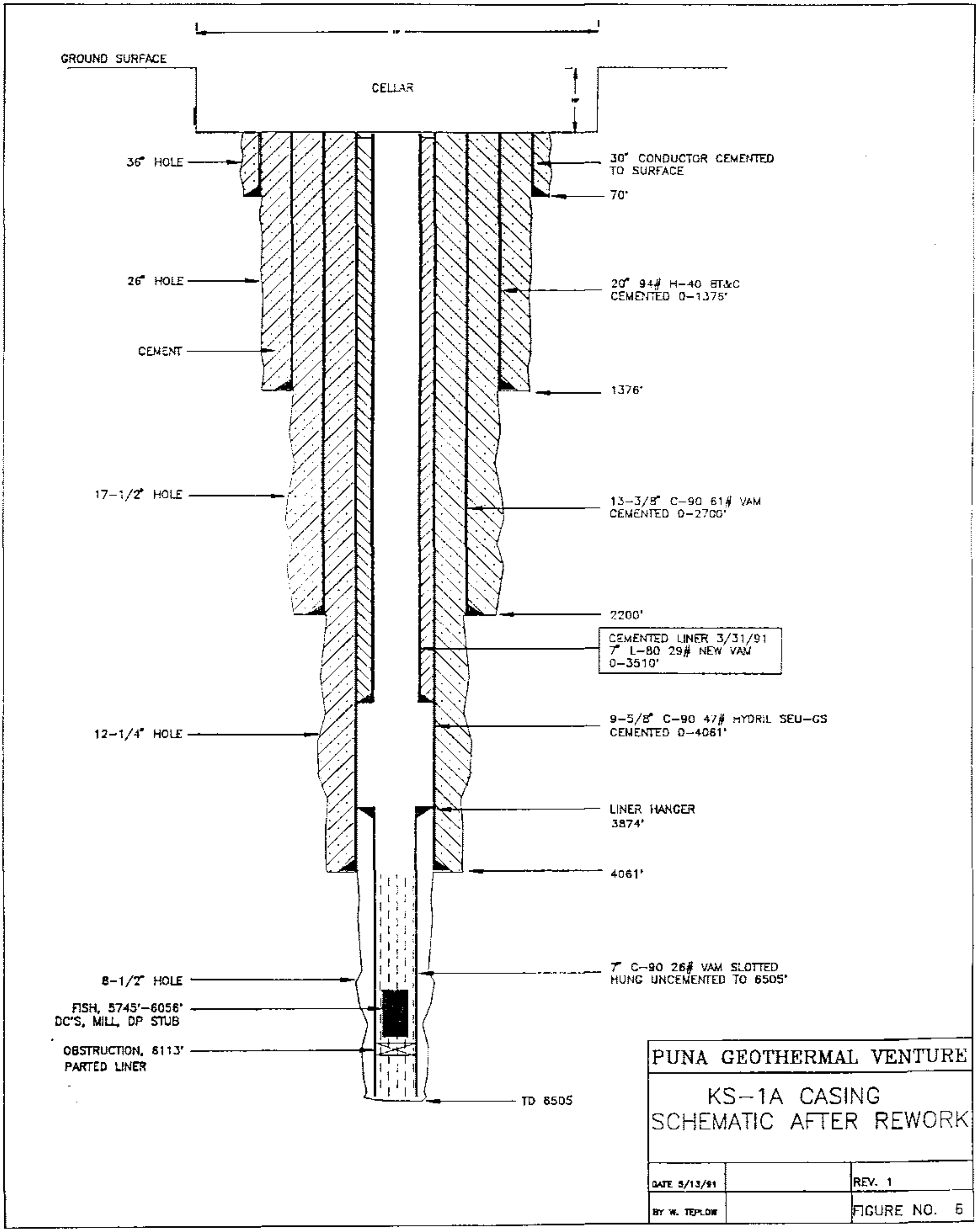

GROUND SURFACE
CELLAR
36" HOLE
30" CONDUCTOR CEMENTED TO SURFACE
70'
26" HOLE
20" 94# H-40 BT&C CEMENTED 0-1375'
CEMENT
1376'
17-1/2" HOLE
13-3/8" C-90 61# VAM CEMENTED 0-2700'
2200'
CEMENTED LINER 3/31/91
7" L-80 29# NEW VAM
0-3510'
12-1/4" HOLE
9-5/8" C-90 47# HYDRIL SEU-GS CEMENTED 0-4061'
LINER HANGER 3874'
4061'
8-1/2" HOLE
7" C-90 26# VAM SLOTTED HUNG UNCEMENTED TO 6505'
FISH, 5745'-6056' DC'S, MILL, DP STUB
OBSTRUCTION, 6113' PARTED LINER
TD 6505
PUNA GEOTHERMAL VENTURE
KS-1A CASING
SCHEMATIC AFTER REWORK
DATE 5/13/91
BY W. TEPLOW
REV. 1
FIGURE NO. 5

TABLE 1

Puna Geothermal Venture Project
Geothermal Resource Permit Application Amendment

Composite Geothermal Fluid Chemical Composition

Element	Brine[a] (ppmw)	Steam Condensate[a] (ppmw)
Na	600 - 10,000	0.17
K	123 - 2,700	0.1
Ca	40 - 920	0.1
Mg	1 - 2	<0.1
Fe	<1 - 8.4	0.05
Mn	<1 - 8.5	-
B	4 - 11	<0.5
Br	40 - 80	-
I	<20	-
F	0.2 - 0.9	-
Li	1 - 9	<0.01
Cl	925 - 21,000	<2
NH	<0.01 - 0.10	0.12
SO_3[b]	9.2 - 24	13
Hg	<0.001 - <0.05	-
As	0.09 - 0.4	<0.01
S[c]	5 - 100	-
Total Alkalinity	≤10	<10
HCO_3	0 - 18	0
CO_3	0	0
SiO_2	420 - 1,500	0.7
TSS	70	-
TDS[d]	2,500 - 35,000	15
pH	≤5 - 5.5	3.5
Conductivity (mhos/cm)	3,100 - 67,000	120
Density	1.03	-

Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.

[a]Wellhead pressure = 155 psig;
Wellhead temperature = 368°F
[b]Concentration high due to oxidation of $S^=$ to SO_4
[c]Concentration low due to oxidation of $S^=$ to SO_4
[d]TDS = Total Dissolved Solids

TABLE 2

PUNA GEOTHERMAL VENTURE
COMPARISON OF WATER CHEMISTRIES
KS-3, KS-1A, PGV MONITOR WELLS
AND PUNA DISTRICT WATER SUPPLY WELLS

	Monitor Wells		Public Water Wells		KS-3	KS-1A
Constituents (mg/l)	MW-1	MW-2	Pahoa	Kapoho	Brine	Brine
Arsenic	ND	ND	ND	ND	ND	ND
Selenium	ND	ND	ND	ND	ND	ND
Mercury	0.0002	0.0005	0.0004	0.0005	NA	NA
Cadmium	ND	ND	ND	ND	ND	ND
Lead	ND	ND	ND	ND	ND	ND
Chromium	ND	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	104.75	ND
Silver	ND	ND	ND	ND	ND	ND
Lithium	0.05	0.08	ND	ND	16.28	7.70
Boron	0.13	0.18	0.13	0.13	23.34	8.40
Silica	102.00	9.10	55.80	58.30	1399.16	1390.00
Sodium	58.20	228.00	20.00	74.60	22674.93	9805.00
Vanadium	0.02	ND	0.04	0.11	ND	ND
Nickel	ND	ND	ND	ND	ND	ND
Bromide	ND	ND	ND	ND	ND	ND
Nitrate	0.37	0.04	0.42	2.64	NA	NA
Fluoride	0.31	1.18	0.29	0.23	2.00	ND
Chloride	19.40	401.00	5.50	91.00	50100.00	19465.00
Calcium	19.20	24.00	3.02	34.10	3948.92	838.00
Magnesium	12.50	12.00	2.76	20.60	58.32	0.00
Potassium	10.60	19.00	2.70	7.03	5288.01	2400.00
pH	7.67	7.68	7.79	7.67	3.58	4.60
T.D.S.	526.00	1036.00	195.00	580.00	85800.00	33929.00

ND: Not detected NA: Not Available

Samples from MW-1, MW-2, Pahoa and Kapoho Wells collected March 19-20, 1991

Samples of Brine from KS-3 collected during Flow Test on March 31, 1991.
Wellhead pressure = 236 psig Wellhead temperature = 395 oF

Samples of Brine from KS-1A collected during Flow Test on October 24, 1985.
Wellhead pressure = 155 psig Wellhead temperature = 365 oF

TABLE 3

PUNA GEOTHERMAL VENTURE NONCONDENSABLE GAS COMPOSITIONS: COMPARISON OF KAPOHO STATE 3, KAPOHO STATE 1A AND OTHER PUNA GEOTHERMAL WELLS

Constituent (ppmw)	KS-3 3/31/91	KS-1A 10/24/85	Composite Wells	Power Plant Design Composition
Carbon Dioxide	487.00	430.00	250 - 1,042	600
Hydrogen Sulfide	654.00	1000.00	800 - 1,300	1300
Ammonia	0.17	<1.3	-	-
Argon	0.30	3.10	6 - 13	-
Nitrogen	13.10	210.00	10 - 700	50
Methane	1.55	<0.3	-	-
Helium	-	<0.005	<0.009	-
Hydrogen	13.20	10.00	11 - 1,412	20
Radon (pCi/L)		2430.00		
Total NCG	1170.00	1655.00	1500 - 2200	1970

Composite Wells:	KS-1, KS-1A, KS-2 and HGP-A Wellhead pressure = 155 psig Wellhead temperature = 368 oF
KS-3:	Wellhead pressure = 236 psig Wellhead temperature = 395 oF
KS-1A:	Wellhead pressure = 155 psig Wellhead temperature = 365 oF
Power Plant:	Backpressure = 210 psig Temperature = 230 oF

TABLE 4

KAPOHO STATE 1A GEOLOGY SUMMARY

MEASURED DEPTH (K.B.)	LITHOLOGY
Surface to 1386 ft.	No sample; Drilled with no returns
1386 to 2770 ft.	Subbaerial Basalts: Intercalated lava flows, cindery basalts, scoria zones and weathered interfaces. Two types of basalts occur as vesicular and non-vesicular flows: 1. Olivine-Tholeiitic basalt: rare to trace, locally common, phenocrysts of olivine and subordinate plagioclase in an aphanitic to glassy groundmass. 2. Differentiated Tholeiitic basalts: porphyritic with common to abundant phenocrysts of olivine, plagioclase and pyroxene in a fine-grained holocrystalline to hyalocrystalline groundmass composed of microlites of plagioclase, pyroxene and magnetite. Includes a small percentage of intrusive dikes.
2770 to 3790 ft.	Transitional Zone: Hyaloclastites (layered units composed of granular fragments of volcanic glass, locally conglomeritic, derived from basaltic ash eruptions, littoral deposits and black sand deposits) intercalated with differentiated basalts and less commonly tholeiitic basalts. Differentiated basalts represent intrusive dikes or surface flows. Tholeiitic basalts probably deposited as submarine pillow basalts or surface flows.
3790 to 6140 ft.	Submarine Basalts: Tholeiitic pillow basalts, glassy, aphanitic basalt with rare to trace, locally common, phenocrysts of olivine and plagioclase, intercalated with minor units of hyaloclastite. Section is cross-cut by microporphryritic to porpyritic intrusive dikes composed of differentiated basalt, phenocrysts of plagioclase, olivine and pyroxene in a holocrystalline groundmass of plagioclase, pyroxene and magnetite. Coarse-grained diabasic unit of differentiated basalt encountered between 4700 and 4740 ft.
6140 to 6505 ft.	Intrusive Dike Complex: Microporphyritic to porpyritic differentiated intrusive basalts as above with subordinate thin intervals of pillow basalts and hyaloclastite deposits.

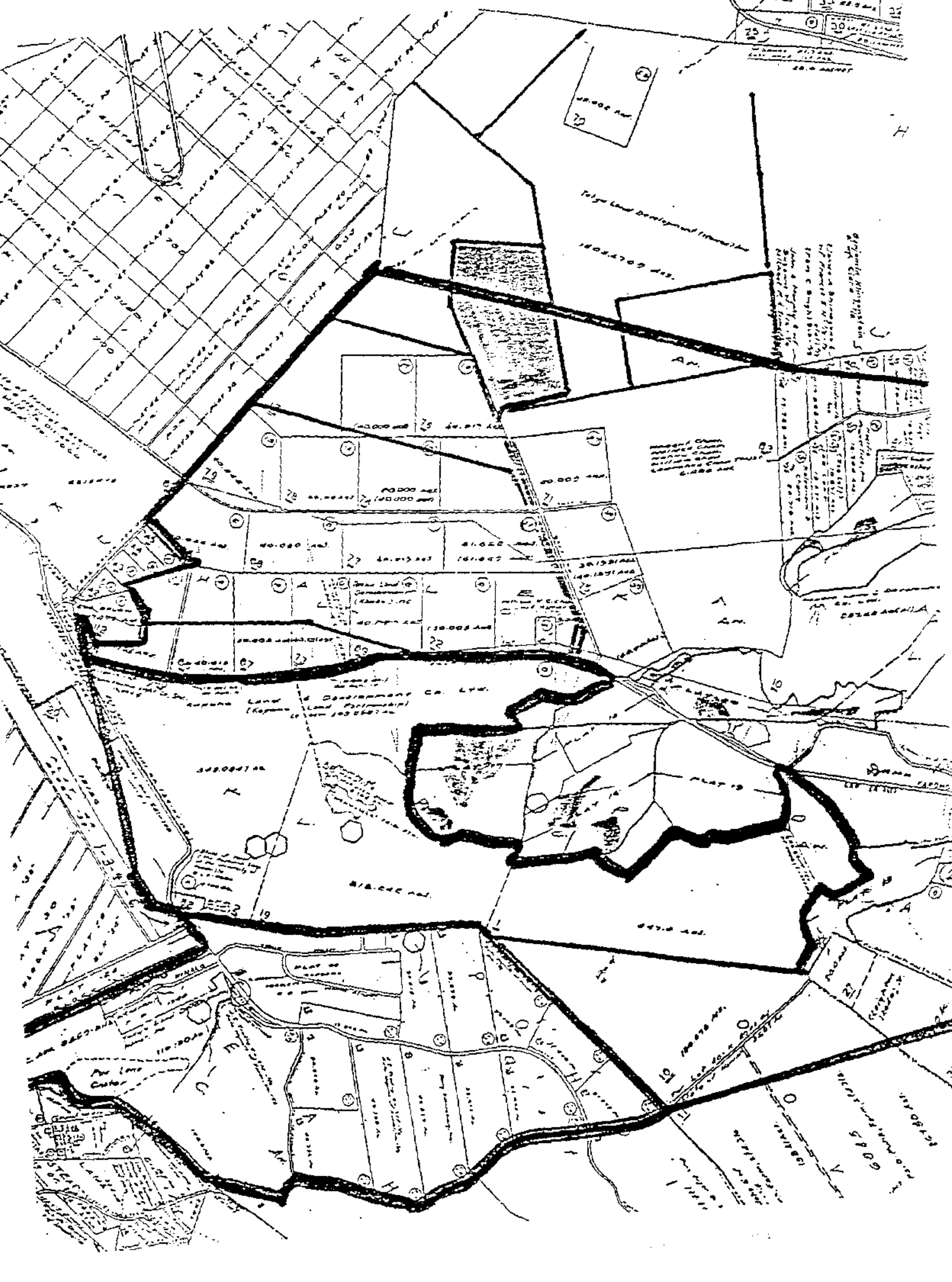
APPENDIX I

GEOTHERMAL RESOURCE SUBZONE
(KAPOHO SECTION)

TAX MAP KEY	AREA (ACRES)	LAND USE CLASSIF.	LAND OWNERS	
✓1-4-01-10(POR.)	258.69	AG/3ac	KAPOHO LAND AND DEV. CO. LTD.	
1-4-01-13	3.21	AG/3ac	KAPOHO LAND AND DEV. CO. LTD.	
			KAPOHO PROPERTIES INC. etal	
1-4-01-21(POR.)	15.95	AG/3ac	MURPHY, JOHN E. etal	
1-4-01-26(POR.)	1.01	AG/3ac	REID, RANDOLPH K./LAURIE B.	
1-4-01-27(POR.)	2.41	AG/3ac	REID, RANDOLPH K. etal	
			WALKER, VIVIAN	
1-4-01-28(POR.)	0.69	AG/3ac	IMAINO, PAUL M.	
1-4-01-31(POR.)	5.44	AG/3ac	SHINDE, YOSHIO/HELENE TRS.	
1-4-01-32(POR.)	5.35	AG/3ac	SHINDE, YOSHIO/HELENE TRS.	
1-4-01-33(POR.)	17.51	AG/3ac	KLINGENSTEIN, CLARA L.	
			R.C. ROBERTS AND CO.	
			KENNY, DUANE	
1-4-01-40(POR.)	8.47	AG/3ac	KLINGENSTEIN, CLARA L.	
1-4-01-41	5.00	AG/3ac	CHOW, WILLIAM PC/HARRIET L.	
1-4-01-46(POR.)	3.54	AG/3ac	MEACHUM, DOUGLAS F./JUDY	
1-4-01-50	10.87	AG/3ac	MARTIN, CARY L.	
1-4-01-51	13.67	AG/3ac	YOZA, ALLAN M.	
1-4-01-52	10.87	AG/3ac	MARTIN, BETTY L.	
1-4-01-53	20.71	AG/3ac	CHANG, KALEONANI S.	
			COLEMAN, KALEONANI	
1-4-01-54(POR.)	13.00	AG/3ac	SHIMOZONO, JAMES A. etal	
1-4-01-55(POR.)	9.39	AG/3ac	PLUMERIA FARMS AND ENT. INC.	
1-4-01-56(POR.)	3.58	AG/3ac	YAMADA, RYUICHI/ A., etal	
			TEASDALE, RAYMOND	
1-4-01-59	26.06	AG/3ac	PERRY, DELAN A./JENNIFER V.	
1-4-01-60	18.74	AG/3ac	HANSHAW, FREDERICK J.	
1-4-01-63(POR.)	3.00	AG/3ac	CHOW, ROBERT etal TR.	
1-4-01-64	585.76	AG/1ac	KAPOHO PROPERTIES INC. etal/BARNWELL IND. INC.	
1-4-01-65	142.54	AG/1ac	INDEX INC. etal	
1-4-01-66(POR.)	73.46	AG/1ac	INDEX INC. etal/ VIKING PROPERTIES INC.	
1-4-01-67(POR.)	64.28	AG/1ac	KAPOHO PROPERTIES INC. etal/BETTENCOURT GEORGE C/E A	
1-4-01-68(POR.)	32.14	AG/1ac	PUNA SUGAR CO. LTD.	
1-4-01-69(POR.)	26.73	AG/1ac	KAPOHO PROPERTIES INC. etal/VIKING PROPERTIES INC.	
1-4-01-70	414.25	AG/3ac	KAPOHO PROPERTIES INC. etal/BARNWELL IND. INC.	
1-4-01-72	0.61	AG	KAPOHO PROPERTIES INC. etal	
1-4-01-81(POR.)	1.17	AG/3ac	REID, RANDOLPH K./ LAURIE B.	
1-4-02-2	1089.30	CONS-L	KAPOHO LAND AND DEV. CO. LTD.	
1-4-02-10	180.47	AG/10ac	DAIICHI SEIKO OF HAWAII INC.	
1-4-02-11	2.69	AG/10ac	STATE OF HAWAII	
✓1-4-02-18	454.89	SPLIT	KAPOHO LAND AND DEV. CO. LTD.	SPLIT:AG/123.52;CONS-L/331.3
1-4-02-27	20.00	AG/10ac	BISHOP B.P. TR. EST.	
			HANOHANO, EPHRAIM K./FELISA	
✓1-4-02-31	303.87	SPLIT	KAPOHO LAND AND DEV. CO. LTD.	SPLIT:AG/256.29;CONS-L/47.58
✓1-4-02-32	444.50	SPLIT	KAPOHO LAND AND DEV. CO. LTD.	SPLIT:AG/357.50;CONS-L/87.00
1-4-02-34(POR.)	323.56	AG/10ac	RICHFIELD OF HAWAII INC. etal	
1-4-02-37(POR.)	36.00	AG/10ac	BISHOP B.P. TR. EST.	
			IKEDA, LEIGHTON	
✓1-4-02-40	48.44	AG/3ac	KAPOHO LAND AND DEV. CO. LTD.	
1-4-02-41	10.08	AG/10ac	KAPOHO LAND AND DEV. CO. LTD.	

CONTINUED ON NEXT PAGE

PRELIMINARY
SUBJECT TO ...



Harrison Engineers

Memorandum to: Bill Teplow, Zvi Reiss, Tom Kizis
From: Roger Harrison
Date: 2 April, 1992
Subject: **Report on Casing Inspection and 12 Hour Injection Test of KS-1A**

1. Summary

Casing inspection surveys and a 12 hour injection test were undertaken on KS-1A between March 14 and 20, 1992 in preparation for converting it to an injection well.

A four arm minimum inside diameter caliper and electromagnetic casing inspection (CIT) tool were run to ascertain the condition of the 7" cemented sleeve from 3510 feet to the surface. The surveys indicated the casing is in good condition with no evidence of scale or corrosion.

The injection test consisted of injecting fresh water supplied from the project site water wells for a continuous period of 12 hours. At the end of the test the well was taking 451 gpm at a wellhead pressure of 208 psi. The injectivity index derived from downhole pressure changes measured after the injection was shut-off was 0.8 gpm/psi.

The power plant injectate is expected to be at a temperature of 200°F. Using the injectivity determined from the test, the calculated injection capacity of the existing KS-1A completion when disposing power plant fluid is 400 gpm at the design wellhead pressure of 150 psi. Alternatively, the injection capacity is 370 gpm if a 5 1/2" liner is hung inside the 7" sleeve.

10 Landscape Road Epsom, Auckland Ph: 64 9 6388693 Fax: 64 9 6315539 New Zealand
1516 Oak Street, #311 Alameda, California 94501 USA

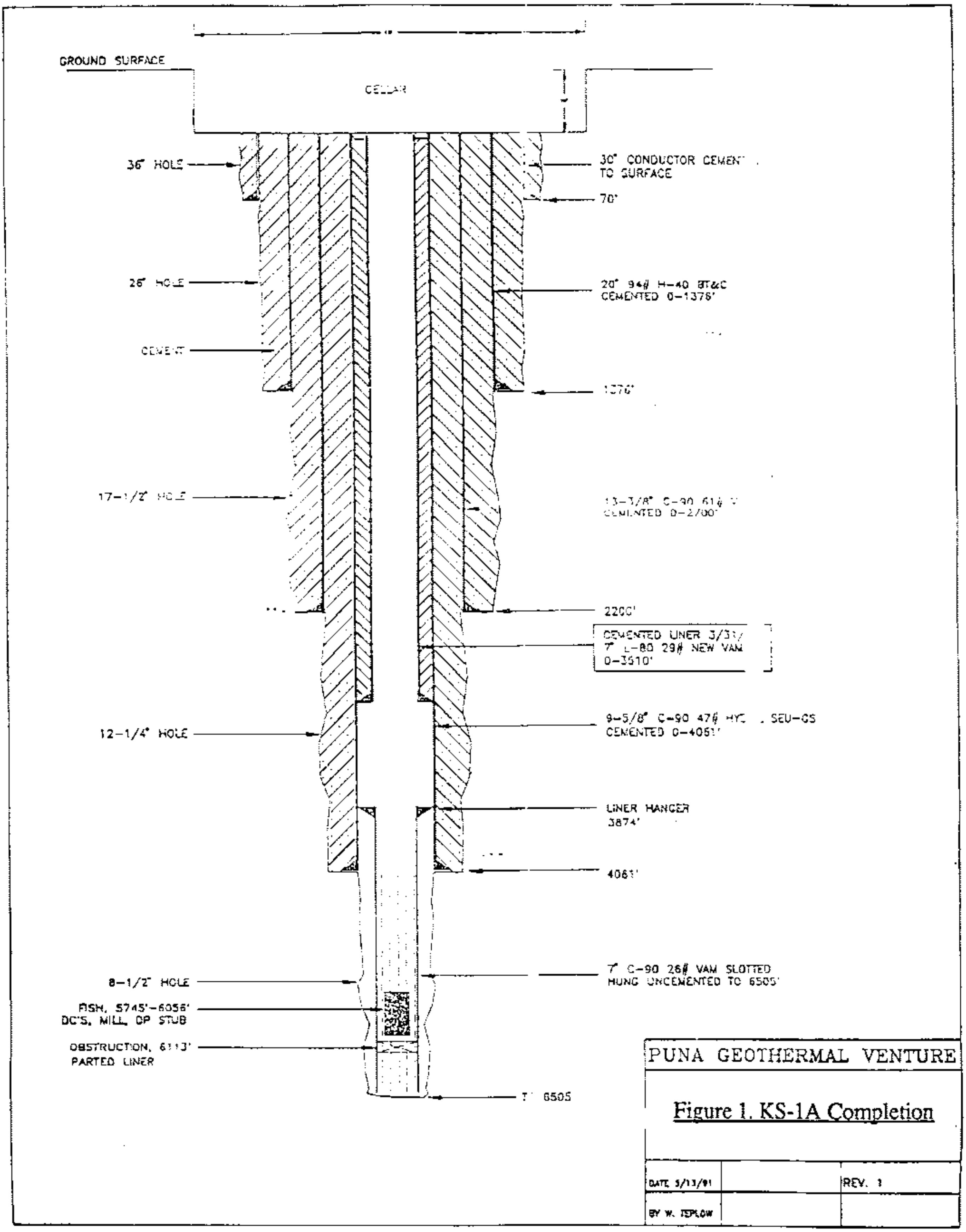


Figure 1. KS-1A Completion

2. Introduction

The well completion of KS-1A is shown in figure 1. A 7" sleeve was cemented inside the original 9 5/8" production casing from the surface to 3510 feet in 1991 in order to repair a damaged connection at 2910 feet and to facilitate rebuilding of the wellhead. The cemented 7" casing was inspected using Halliburton Logging Services instruments and logging equipment on March 14, 1992. A minimum ID log (4 arm caliper) was initially run from the bottom of the 7" sleeve at 3,510 feet to the surface. An electromagnetic casing inspection (CIT) survey was then run through the same interval.

A 12 hour injection test of KS-1A was conducted on 19 March, 1992. The test facilities are shown in figure 2 and comprised two Halliburton pumping units hooked in parallel through temporary piping to the permanent eight inch injection line to KS-1A. Water for the pumps was drawn from a 40,000 gallon Baker tank which was continuously recharged during the test by the two fresh water wells at the project site. The injected water temperature was 104°F. Flowrate was measured using an orifice type flowmeter installed a few feet upstream of the wellhead. Wellhead pressure was measured by a pressure gage installed on the three inch side outlet valve on the wellhead.

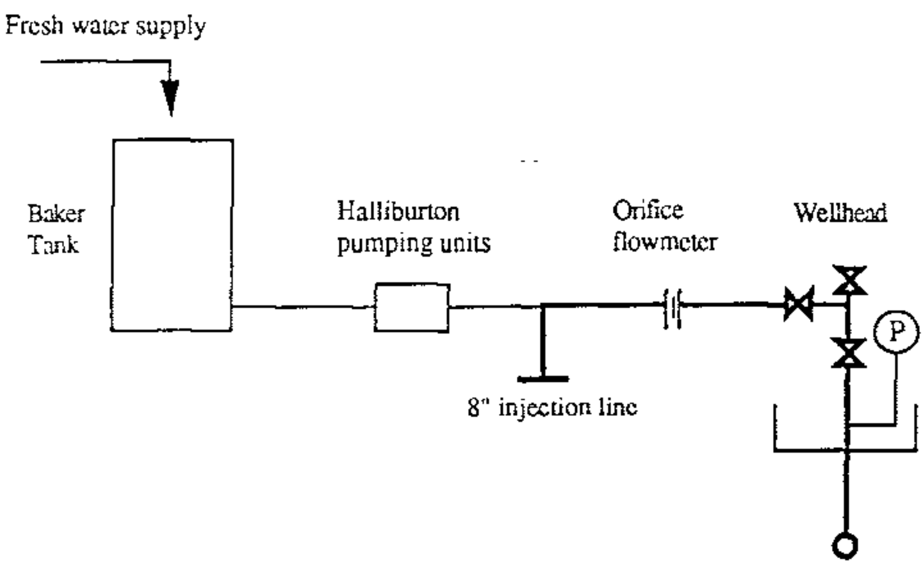


Figure 2. Injection Test Facilities

A number of downhole measurements were conducted during the test. A combination spinner - temperature survey was run in the cemented 7" sleeve during injection to check the mechanical integrity of the casing. Also, a pressure - temperature survey was run to 5,000 feet toward the end of the injection period. The instruments were subsequently suspended at 5,000 feet for 7 hours after injection was terminated to record pressure fall-off.

A further pressure - temperature survey was run on March 20, 1992, about 36 hours after the injection test.

3. Results

3.1 Casing Inspection

The minimum ID caliper and CIT inspection tools indicated the 7" sleeve was in good condition with no evidence of scale or corrosion.

3.2 Injection Test

The flowrate and wellhead pressure recorded during the test are presented in table 1 and figure 3. At the end of the 12 hour pumping period the flowrate was 450 gpm and the wellhead pressure was 208 psig.

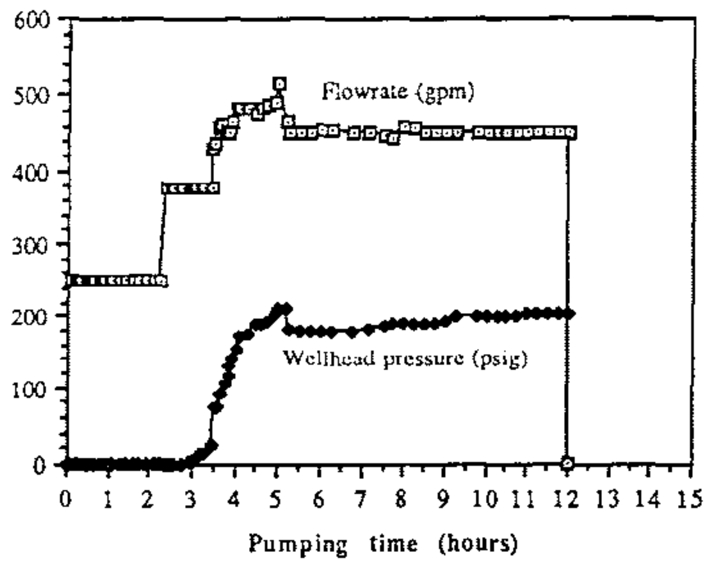


Figure 3. KS-1A 12 hour injection test, 18 March, 1992

Table 1. KS-1A 12 hour injection test data, 18 March, 1992

Time 17-Mar-92	Pumping Time (hrs)	Flowrate (gpm)	Wellhead Pressure (psig)	Injectivity Index (gpm/psi)	Comments
07:45	0.00		0		Start Pumping
07:50	0.08	252	0		Inj. water temp = 104 F
07:55	0.17	252	0		
07:57	0.20	252	0		
08:00	0.25	252	0		
08:05	0.33	252	0		
08:10	0.42	252	0		
08:15	0.50	252	0		
08:20	0.58	252	0		
08:25	0.67	252	0		
08:30	0.75	252	0		
08:35	0.83	252	0		
08:40	0.92	252	0		
08:45	1.00	252	0		
08:50	1.08	252	0		
09:00	1.25	252	0		
09:10	1.42	252	0		
09:20	1.58	252	0		
09:30	1.75	252	0		
09:40	1.92	252	0		
09:50	2.08	252	0		
10:00	2.25	252	0		
10:08	2.38	378	0		
10:15	2.50	378	0		
10:20	2.58	378	0		
10:30	2.75	378	0		
10:40	2.92	378	2		
10:45	3.00	378	2		
10:50	3.08	378	7		
10:55	3.17	378	14		
11:00	3.25	378	15	0.87	
11:10	3.42	378	25	0.85	
11:13	3.47	430		1.03	
11:15	3.50	438	75	0.89	
11:20	3.58	460	75	0.93	
11:25	3.67	464	92	0.91	
11:30	3.75	453	105	0.86	
11:35	3.83	453	116	0.85	
11:36	3.85	453	130	0.83	
11:40	3.92	467	140	0.84	

Table 1. cont'd KS-3 12 hour injection test

Time 17-Mar-92	Pumping Time (hrs)	Flowrate (gpm)	Wellhead Pressure (psig)	Injectivity Index (gpm/psi)	Comments
13:00	5.25	452	185	0.75	
13:15	5.50	452	180	0.75	
13:30	5.75	452	180	0.75	
13:45	6.00	456	180	0.76	
14:00	6.25	456	180	0.76	
14:03	6.30				Start Spinner Survey
14:23	6.63	453	180	0.76	
14:30	6.75	453	180	0.76	
14:54	7.15	453	185	0.75	
15:15	7.50	449	187	0.74	
15:30	7.75	445	190	0.73	
15:45	8.00	458	190	0.75	
16:00	8.25	458	190	0.75	
16:15	8.50	453	190	0.74	
16:30	8.75	451	190	0.74	
16:45	9.00	451	195	0.73	
17:00	9.25	451	200	0.73	
17:30	9.75	453	200	0.73	
17:45	10.00	453	200	0.73	
18:00	10.25	453	200	0.73	
18:15	10.50	453	200	0.73	
18:30	10.75	453	200	0.73	
18:45	11.00	453	205	0.73	
19:00	11.25	453	205	0.73	
19:15	11.50	453	205	0.73	
19:30	11.75	453	205	0.73	
19:45	12.00	453	205	0.73	
19:46	12.02	0			Shut-in

The results of the spinner - temperature survey are presented in table 2. The spinner survey showed a small quantity of flow was lost between 2,000 and 3,000 feet. The change is within the measurement accuracy of the instrument. Since no signs of casing damage were evident on the casing inspection surveys it is concluded that the casing is sound. (Note: the temperature measured by the downhole instruments is about 40°F lower than the actual injected water temperature. This is because the instruments are designed primarily to measure high temperatures and are not accurate when measuring low temperatures.)

Table 2. Spinner - temperature survey while injecting

Depth (feet)	Temperature (F)	Spinner % of flow
1000	64	100
2000	68	100
3000	70	91
3420	71	91

The results of the pressure - temperature survey conducted while injecting are given in table 3 and the pressure fall-off data is given in table 4.

Table 3. Pressure - temperature survey while injecting

Depth (feet)	Temperature (F)	Pressure (psig)
1000	65	611
2000	69	1038
3000	70	1461
4000	73	1877
5000	80	2305

Table 4. Pressure fall-off (at 5,000 feet) after injection

Time (minutes)	Pressure (psig)	Temperature (F)
0	2305	80
10	2205	90
20	2133	95
30	2092	100
90	1955	116
150	1896	127
210	1868	136
270	1846	141
330	1836	147
390	1827	154
450		160
506	1814	171

The pressure and temperature changes at 5,000 feet are plotted in figure 4.

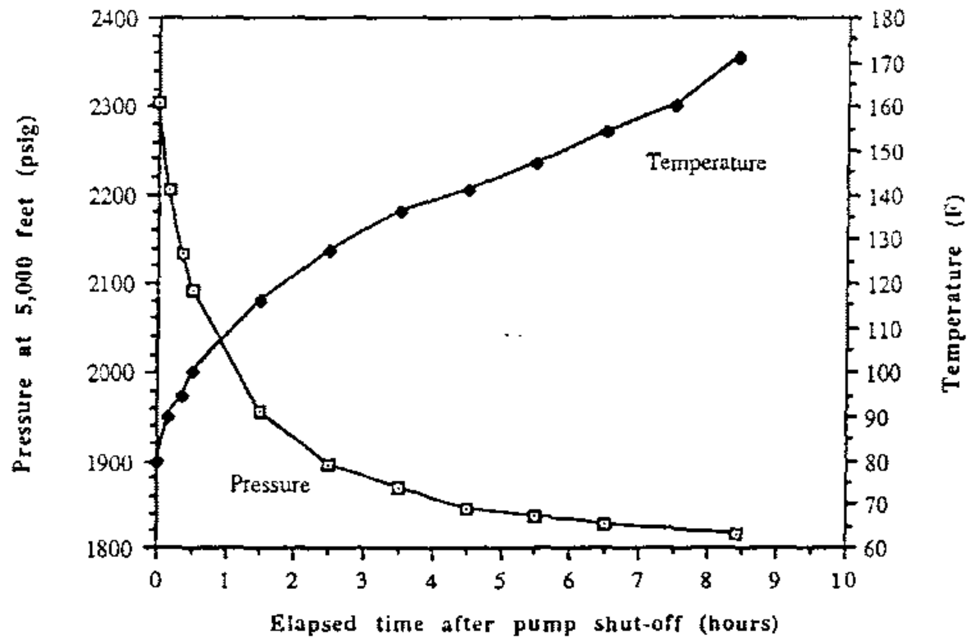


Figure 4. Pressure and Temperature changes at 5,000 feet after pump shut-off

A Horner plot of the pressure fall-off data is shown in figure 5. The calculated flow capacity is 14,800 md-ft/cp which indicates the reservoir in the vicinity of KS-1A has low permeability.

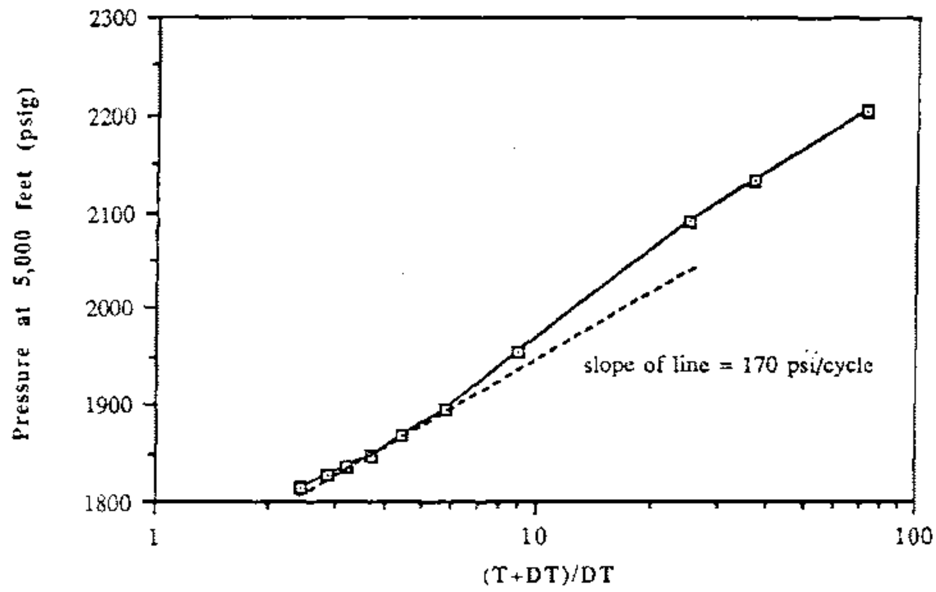


Figure 5. Horner plot of fall-off data

The pressure and temperature survey conducted on March 20, 1992, approximately 36 hours after the injection test is presented in table 5.

Table 5. Static pressure - temperature survey 20 March, 1992, 1 day after injection test

Depth (feet)	Temperature (F)	Pressure (psig)
500	52	
1000	57	136
1500	78	348
2000	108	566
2500	112	781
3000	179	985
3200	233	1060
3400	268	1137
3600	295	1779
3800	318	1309
4000	321	1389
4200	322	1430
4400	322	1502
4600	322	1578
4800	311	1650
5000	277	1722

The temperature data is plotted on figure 7. The survey exhibits a temperature reversal below 4600 feet. This indicates most of the injected water was leaving the well below this depth.

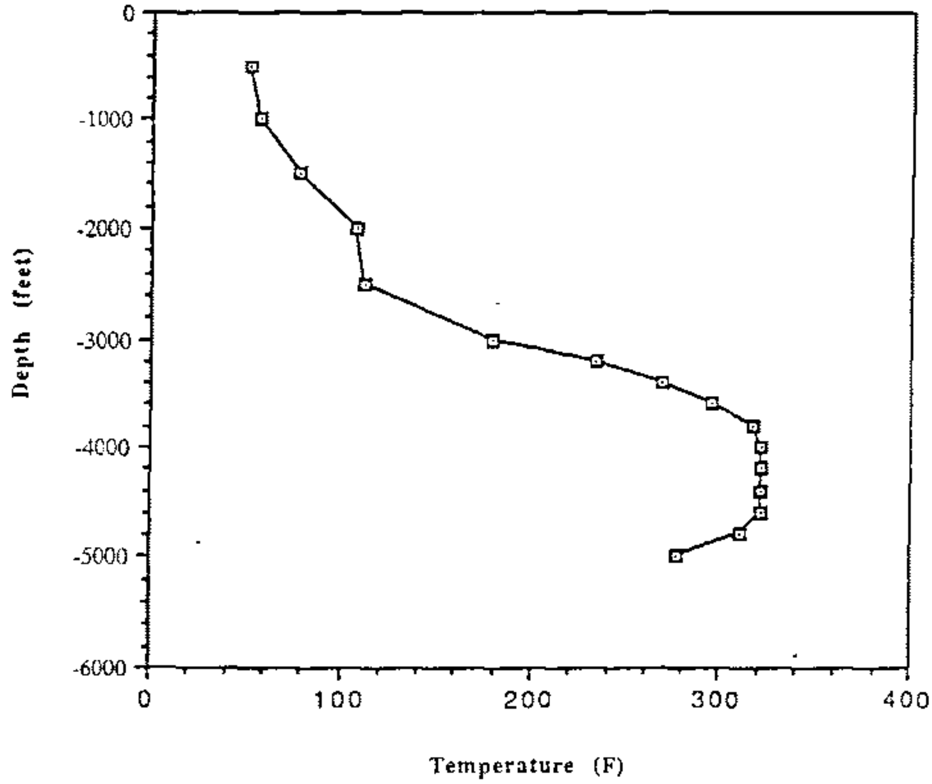


Figure 7. Static pressure - temperature survey, 20 March,1992 - 1 day after injection

The measured pressure at 5,000 feet on March 20 was 1722 psig. The total pressure change at 5,000 feet over the 36 hours or so between shutting-off injection and the March 20 survey was therefore; 2305 - 1722 = 583 psi. The injectivity index given by this is; 451 gpm / 583 psi = 0.8 gpm/psi. The injectivity index calculated for the portion of the test during which the well exhibited a positive wellhead pressure is on table 1.

4. Injection Capacity when Disposing of Power Plant Fluids

The injection capacity (Q) can be expressed as follows:

$$Q = II * [WHP + WD * \rho / 144 - SP - FP]$$

where;

Q = injection flowrate (gpm)
II = injectivty index (gpm/psi)
WHP = wellhead pressure (psig)
WD = well depth to injection zone (ft)
ρ = density of injection fluid (lb/ft^3)
SP = static pressure at injection zone (psig)
FP = wellbore friction pressure drop of fluid being injected (psi)

The power plant injection fluids will be single phase liquid (noncondensible gases will be in solution at the injection pressure) at a temperature of 200°F. In the case of KS-1A, the measured injectivity index (II) is 0.8 gpm/psi, the design injection wellhead pressure (WHP) is 150 psig, the well depth to the injection zone (WD) is assumed to be 5,000 feet, the injection fluid density (ρ) is 60.1 lb/ft^3 and the static pressure at the injection zone (SP) is 1722 psig. For the conditions relevant to this case the friction pressure drop can be expressed as follows;

$$FP = 0.91 * Q^2 / d^5$$

where d = effective internal diameter (inches)

For the existing completion (effective internal diameter approximately 6.6"), the calculated injection capacity of KS-3 is 400 gpm. For a completion with a 5 1/2" liner hung from the surface to 3,510 feet (effective internal diameter approximately 5.2") the injection capacity is 370 gpm.

Harrison Engineers

Memorandum to:	Bill Teplow, Zvi Reiss, Tom Kizis
From:	Roger Harrison
Date:	30 March, 1992
Subject:	**Report on Casing Inspection and 12 Hour Injection Test of KS-3**

1. Summary

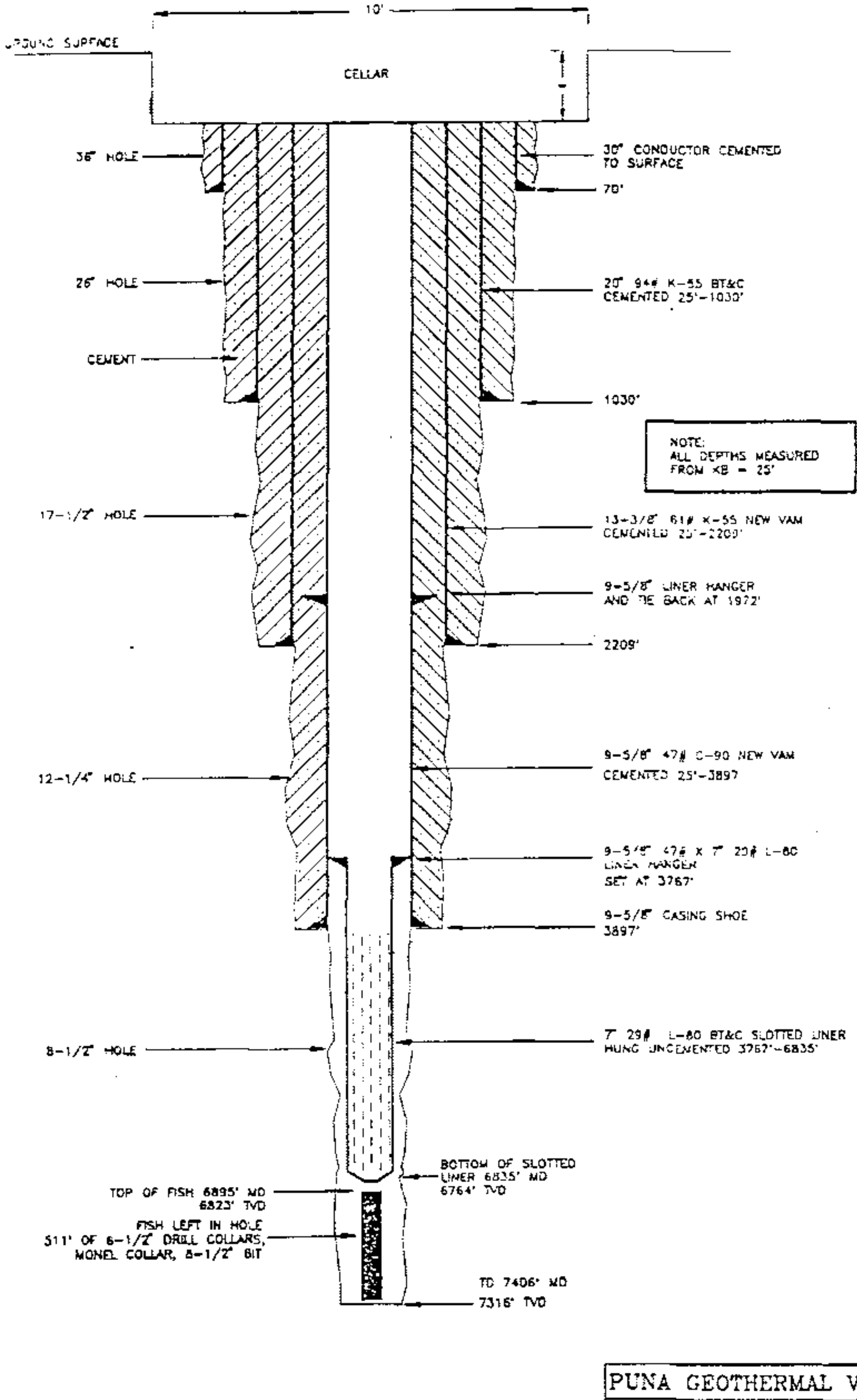
Casing inspection surveys and a 12 hour injection test were undertaken on KS-3 between March 13 and 19, 1992 in preparation for converting it to an injection well.

A four arm minimum inside diameter caliper and electromagnetic casing inspection (CIT) tool were run to ascertain the condition of the 9 5/8" cemented casing. The surveys indicated the casing was generally in good condition apart from the interval between 2,490 feet and 2,520 feet which exhibited significant corrosion on the outside (i.e. formation) side of the casing. At its worst point the corrosion has resulted in a reduction of up to 50 percent of the original pipe wall thickness. The casing inspection surveys and spinner - temperature surveys run during and after the subsequent injection test did not reveal any holes or leaks in the casing.

The injection test consisted of injecting fresh water supplied from the project site water wells for a continuous period of 12 hours. The maximum flowrate achieved during the test was 820 gpm at a wellhead pressure of 153 psi. The injectivity index derived from downhole pressure changes measured after the injection was shut-off was 1.7 gpm/psi.

The power plant injectate is expected to be at a temperature of 200°F. Using the injectivity determined from the test, the calculated injection capacity of the existing KS-3 completion when disposing power plant fluid is 760 gpm at the design wellhead pressure of 150 psi. Alternatively, the injection capacity is 715 gpm if a 7" liner is hung inside the 9 5/8" casing. These injection capacities are probably conservative. Establishment of a cool plume around the well with long term injection will likely produce a gradual increase in injection capacity.

10 Landscape Road Epsom, Auckland Ph: 64 9 6388693 Fax: 64 9 6315539 New Zealand
1516 Oak Street, #311 Alameda, California 94501 USA



PUNA GEOTHERMAL VENTURE

KS-3 COMPLETION

DATE 4/7/91		REV. 1
BY W. TEPLOW	FILE: PGV\KS3COMPL.DWG	FIGURE NO. 1

2. Introduction

The cemented 9 5/8" casing was inspected using Halliburton Logging Services instruments and logging equipment on March 13, 1992. A minimum ID log (4 arm caliper) was initially run from the top of the 7" liner at 3,767 feet to the surface (refer to well diagram in figure 1). An electromagnetic casing inspection (CIT) survey was then run from the top of the liner to the surface.

A 12 hour injection test of KS-3 was conducted on 17 March, 1992. The test facilities are shown in figure 2 and comprised two Halliburton pumping units hooked in parallel through temporary piping to the permanent eight inch injection line to KS-3. Water for the pumps was drawn from a 40,000 gallon Baker tank which was continuously recharged during the test by the two fresh water wells at the project site. The injected water temperature was 105°F. Flowrate was measured using an orifice type flowmeter installed a few feet upstream of the wellhead. Wellhead pressure was measured by a pressure gage installed on the three inch side outlet valve on the wellhead.

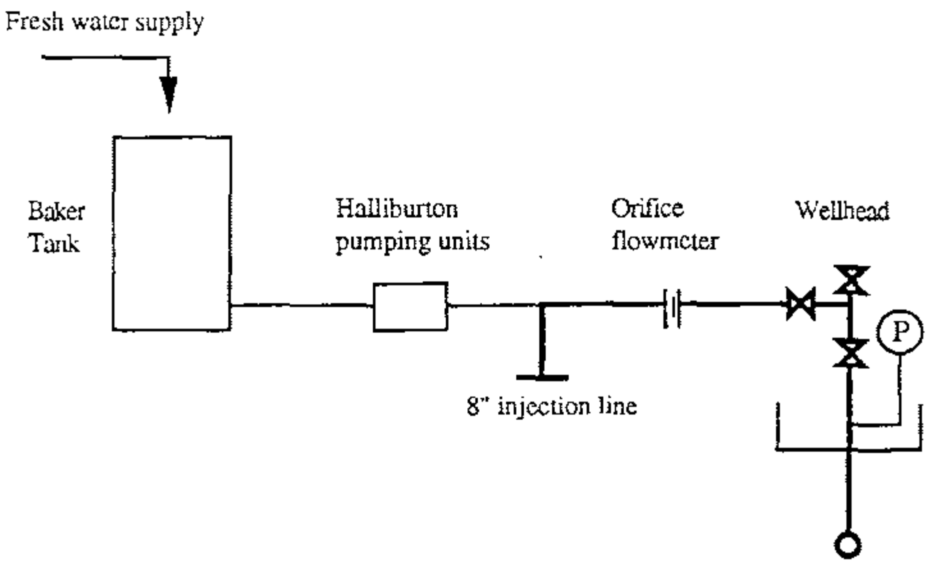


Figure 2. Injection Test Facilities

A number of downhole measurements were conducted during the test. A combination spinner - temperature survey was run in the cemented casing portion of the well during injection to check the mechanical integrity of the casing. Also, a pressure - temperature survey was run to 5,000 feet toward the end of the injection period. The instruments were subsequently suspended at 5,000 feet for 7 hours after injection was terminated to record pressure fall-off.

A further pressure - temperature survey was run on March 19, 1992 , about 36 hours after the injection test.

3. Results

3.1 Casing Inspection

The minimum inside diameter (ID) caliper did not reveal any failures in the 9 5/8" casing. A gradual reduction in ID with increasing depth was evident; from about 8.65" at the surface to about 8.3" at 3,767 feet (note; nominal pipe ID is 8.68"). This could be due to the presence of scale formed during the flow-test or possibly a small calibration drift in the instrument (not uncommon). The caliper indicated an anomalous increase in inside diameter on one axis between 2490 feet and 2520 feet, although the maximunm ID registered was still within the nominal ID of the pipe.

The CIT survey also indicated the casing was generally in good condition apart from the interval between 2490 feet and 2520 feet. The interval in question is shown in figure 3. Corrosion of the outside of the pipe has resulted in the loss of about half the pipe wall thickness at it's worst point. The corrosion is probably due to the presence of acidic fluids in the formation. The caliper and CIT did not identify any holes in the pipe.

3.2 Injection Test

The flowrate and wellhead pressure recorded during the test are presented in table 1 and figure 4. At the end of the 12 hour pumping period the flowrate was 820 gpm and the wellhead pressure was 153 psig.

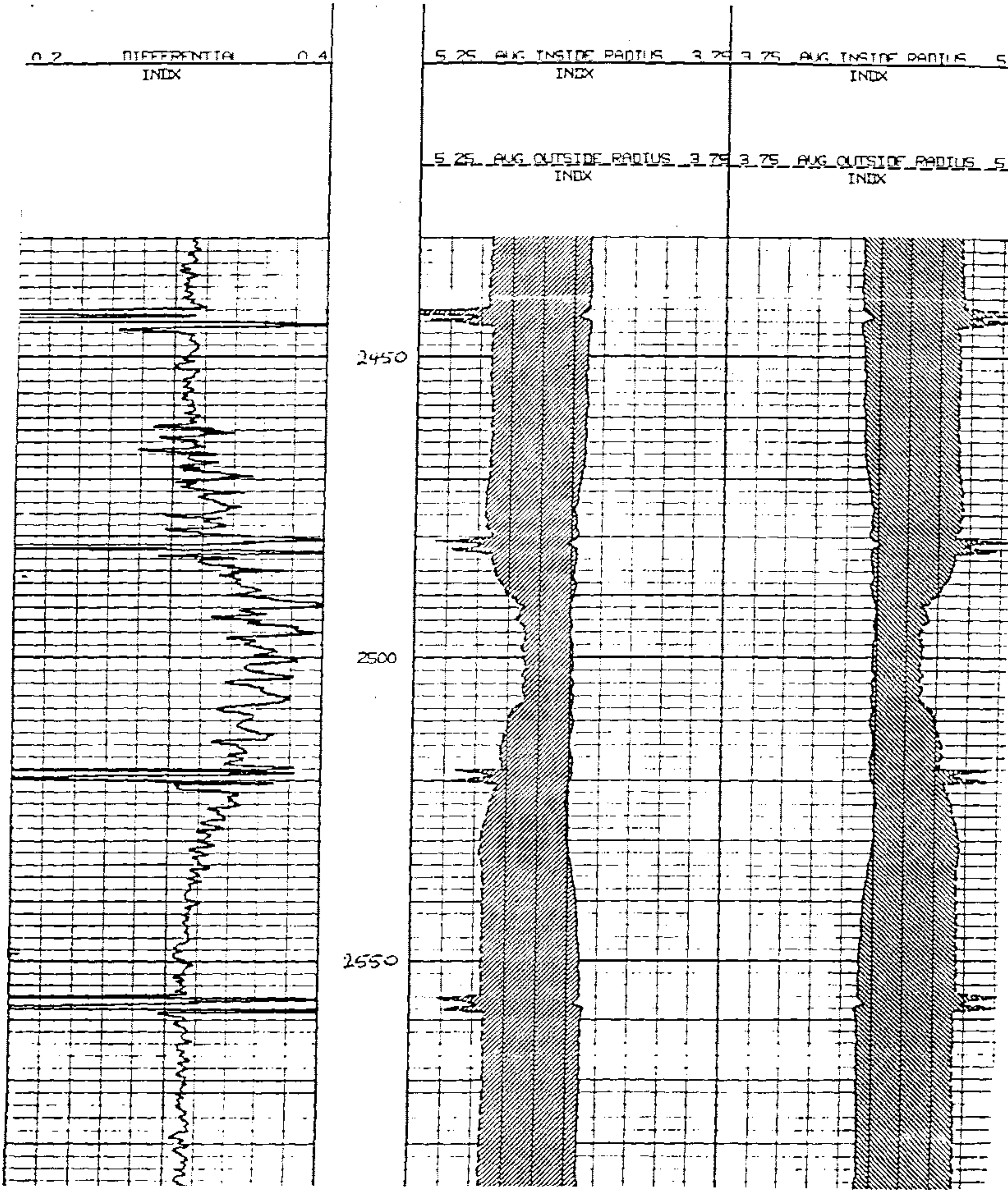


Figure 3. Portion of CIT Log showing corrosion in 9 5/8" casing

Table 1. KS-3 12 hour injection test data, 17 March, 1992

Time 17-Mar-92	Pumping Time (hrs)	Flowrate (gpm)	Wellhead Pressure (psig)	Injectivity Index (gpm/psi)	Comments
06:58	0.00		0		Start Pumping
07:00	0.03	252	0		Inj. water temp = 105F
07:05	0.12	252	0		
07:10	0.20	252	0		
07:15	0.28	252	0		
07:20	0.37	252	0		
07:26	0.47	504	0		
07:32	0.57	504	0		
07:37	0.65	500	0		
07:42	0.73	502	0		
07:47	0.82	510	0		
07:52	0.90	505	0		
07:57	0.98	505	0		
08:00	1.03	505	0		
08:05	1.12	505	0		
08:10	1.20	505	0		
08:15	1.28	500	0		
08:20	1.37	520	0		
08:25	1.45	525	0		
08:30	1.53	520	0		
08:35	1.62	520	0		
08:40	1.70	530	0		
08:45	1.78	530	0		
08:50	1.87	530	0		
08:55	1.95	530	0		
09:00	2.03	530	0		
09:05	2.12	530	0		
09:10	2.20	530	0		
09:15	2.28	530	0		
09:18	2.33	710	0		
09:22	2.40	750	48	1.83	
09:25	2.45	750	65	1.76	
09:30	2.53	750	77	1.71	
09:35	2.62	715	87	1.60	
09:40	2.70	750	98	1.63	
09:45	2.78	750	103	1.62	
09:50	2.87	745	106	1.60	
09:55	2.95	745	108	1.59	
10:00	3.03	740	109	1.58	
10:05	3.12	740	112	1.57	
10:10	3.20	735	112	1.55	
10:15	3.28	735	114	1.55	
10:20	3.37	735	114	1.55	
10:25	3.45	735	116	1.54	
10:30	3.53	735	118	1.54	
10:33	3.58	830	155	1.61	
10:37	3.65	840	158	1.62	
10:40	3.70	795	140	1.59	
10:45	3.78	795	152	1.55	

Table 1. cont'd KS-3 12 hour injection test

Time 17-Mar-92	Pumping Time (hrs)	Flowrate (gpm)	Wellhead Pressure (psig)	Injectivity Index (gpm/psi)	Comments
10:50	3.87	800	154	1.55	
10:55	3.95	800	155	1.55	
11:00	4.03	795	156	1.54	
11:10	4.20	800	160	1.54	
11:20	4.37	800	162	1.53	
11:30	4.53	805	165	1.53	
11:40	4.70	810		2.25	
11:50	4.87	800	163	1.53	
12:00	5.03	810	165	1.54	
12:10	5.20	810	160	1.56	
12:20	5.37	815	163	1.56	
12:30	5.53	810	163	1.55	
12:40	5.70	810	163	1.55	
12:50	5.87	815	163	1.56	
13:00	6.03	805	163	1.54	
13:10	6.20	805	157	1.55	
13:20	6.37	805	157	1.55	
13:40	6.70	800	157	1.55	
13:50	6.87	800	156	1.55	
14:00	7.03	805	156	1.56	
14:10	7.20	805	153	1.57	
14:20	7.37	800	150	1.57	
14:30	7.53	800	151	1.56	
11:40	4.70	805	152	1.57	
14:53	7.92	805	152	1.57	Start spinner survey
15:00	8.03	805	150	1.58	
15:10	8.20	800	147	1.58	
15:20	8.37	800	148	1.57	
15:30	8.53	800	148	1.57	
15:40	8.70	800	147	1.58	
15:50	8.87	795	143	1.58	
16:00	9.03	805	145	1.59	
16:10	9.20	810	150	1.59	
16:20	9.37	840	148	1.65	
16:30	9.53	805	150	1.58	
16:40	9.70	805	150	1.58	
16:50	9.87	812	148	1.60	
17:00	10.03	820	156	1.59	
17:10	10.20	795	158	1.53	
17:20	10.37	820	158	1.58	
17:30	10.53	820	158	1.58	
17:40	10.70	820	158	1.58	
17:50	10.87	815	156	1.58	
18:00	11.03	820	156	1.59	Start P/T survey
18:10	11.20	825	156	1.60	
18:20	11.37	820	152	1.60	
18:30	11.53	820	154	1.59	
18:40	11.70	825	153	1.61	
18:50	11.87	820	155	1.59	
19:00	12.03	820	153	1.60	
19:01	12.05	0			Shut-in

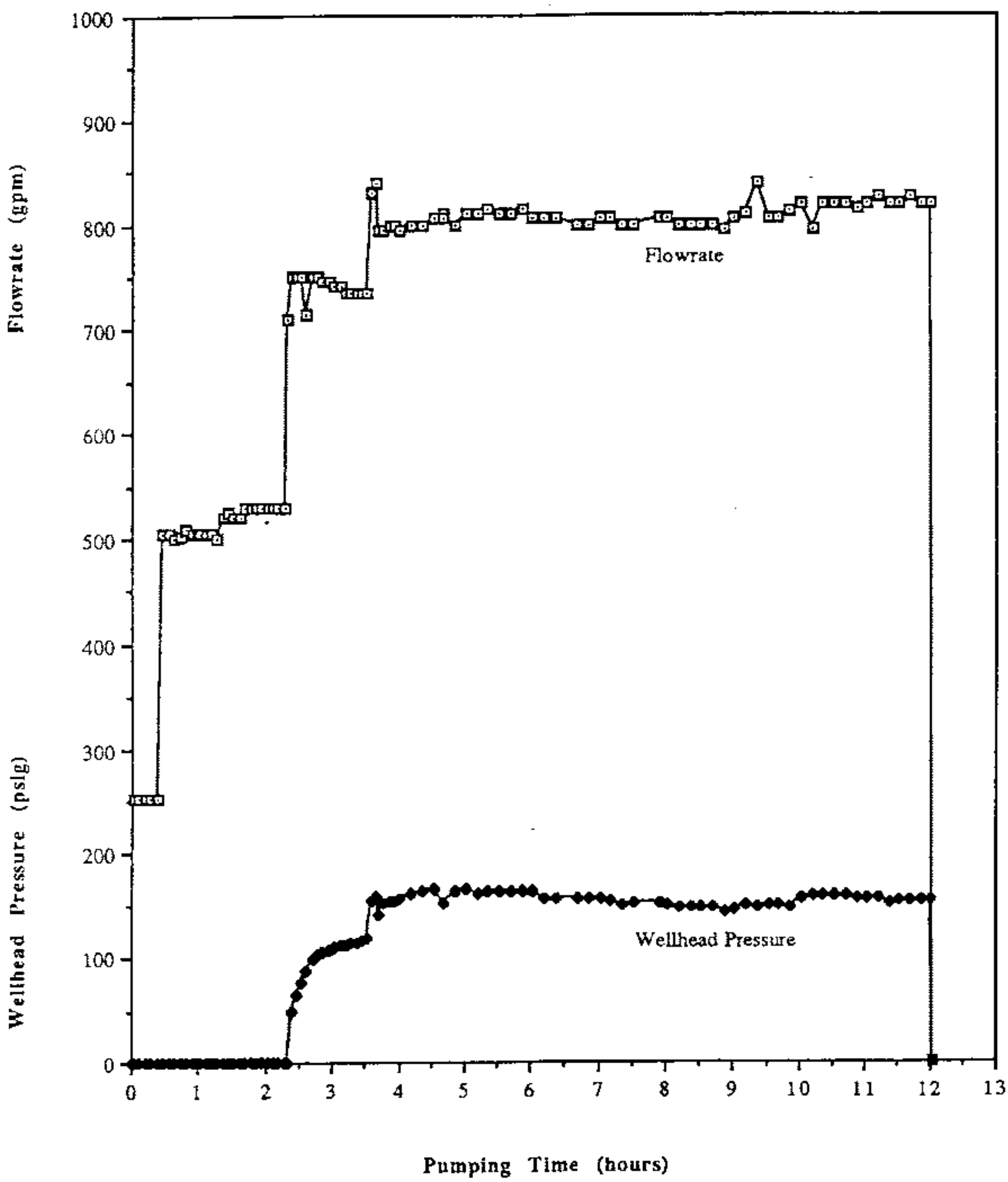


Figure 4. KS-3 12 hour injection test data, 17 March, 1992

The results of the spinner - temperature survey are presented in table 2. The survey showed no flow was lost between the surface and the bottom of the cemented casing, and therefore there were no leaks in the casing.

Table 2. Spinner - temperature survey while injecting

Depth (feet)	Temperature (F)	Spinner % of flow
1000	57	100
2000	67	100
2400	69	100
2500	69	100
2600	69	100
3000	69	100
3720	70	100

The results of the pressure - temperature survey conducted while injecting are given in table 3 and the pressure fall-off data is given in table 4.

Table 3. Pressure - temperature survey while injecting

Depth (feet)	Temperature (F)	Pressure (psig)
2000	53	1003
2400	63	1175
2600	68	1260
3000	68	1487
4000	69	1849
5000	70	2258

Table 4. Pressure fall-off after injection

Time (minutes)	Pressure (psig)	Temperature (F)
0	2261	70
10	1952	74
20	1896	80
30	1864	89
60	1818	135
120	1808	167
180		193
240		214
300		231
360		245
420		
440	1786	260

The pressure fall-off and temperature change at 5,000 feet is also plotted in figure 5. The total pressure fall-off at 5,000 feet recorded 7 hours after shut-in was 475 psi. The injection flowrate prior to shut-in was 820 gpm, therefore the approximate injectivity index was; 820 gpm / 475 psi = 1.7 gpm/psi.

The injectivity index calculated for the portion of the test during which the wellhead pressure exceeded zero is shown on table 1. Inspection of the table shows the injectivity index was roughly constant during the test.

A Horner plot of the pressure fall-off data is shown in figure 6. Simple quantitative analysis of the data is not appropriate in this case due to the complications produced by large temperature changes (see Figure 5), and probable boiling or condensation transients in the reservoir.

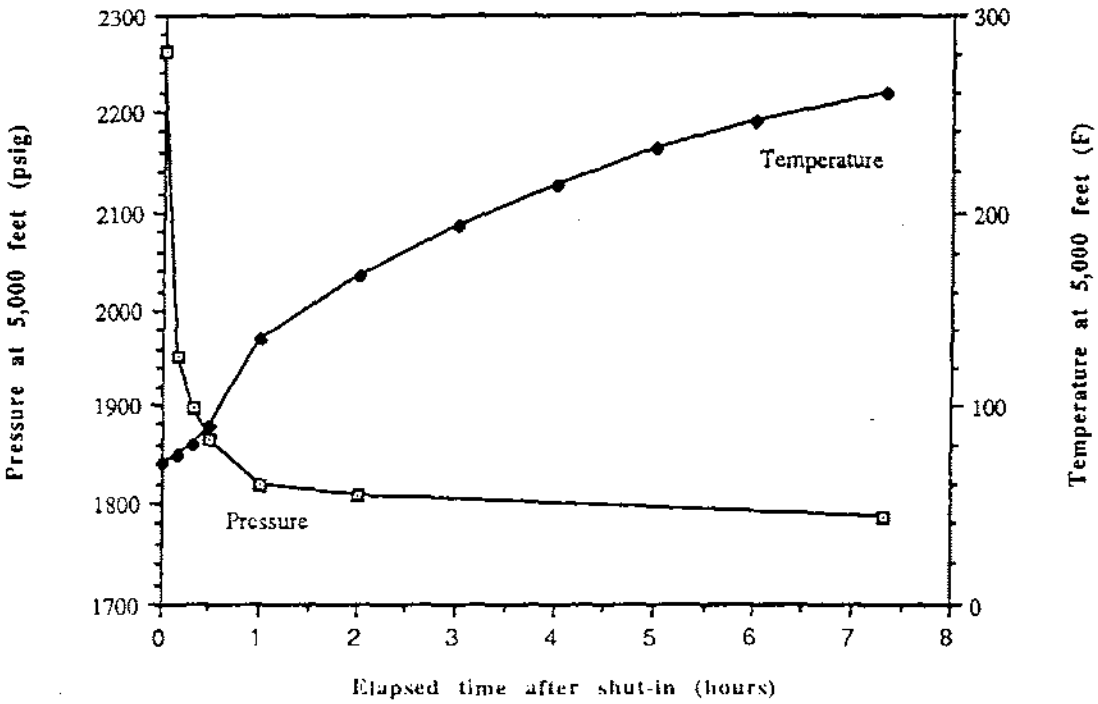


Figure 5. Pressure and temperature changes at 5,000 feet after shutting off injection

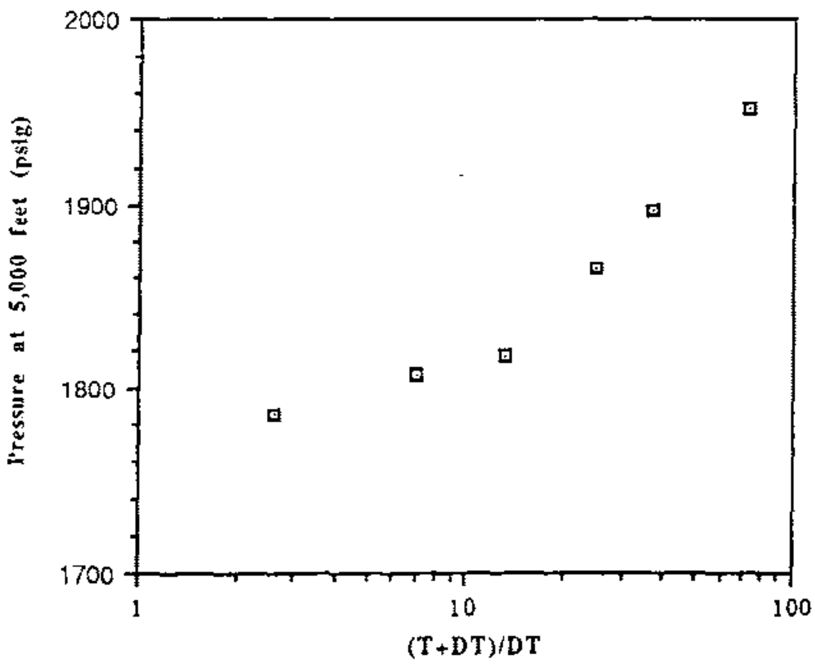


Figure 6. Horner plot of pressure fall-off data

The pressure and temperature survey conducted on March 19, 1992, approximately 36 hours after the injection test is presented in table 5.

Table 5. Static pressure - temperature survey 19 March, 1992, 1 day after injection test

Depth (feet)	Temperature (F)	Pressure (psig)
1000	53	133
2000	61	569
2400	74	744
2500	89	
2600	95	834
2800	159	
3000	215	1000
4000	251	1390
5000	320	1779

The temperature data is plotted on figure 7 along with the static survey of 24 March, 1991 when the well was in temperature equilibrium. The March 19 survey shows the well is still warming after the injection test. However, it displays the same general shape as the equilibrium survey indicating the temperature profile was returning to the original equilibrium condition.

The measured pressure at 5,000 feet on March 19 was 1779 psig. This is similar to the pressure of 1786 measured 7 hours after shut-in (see table 4). The injectivity index given by this pressure is; 820 gpm / (2261 - 1779) psi = 1.7 gpm/psi.

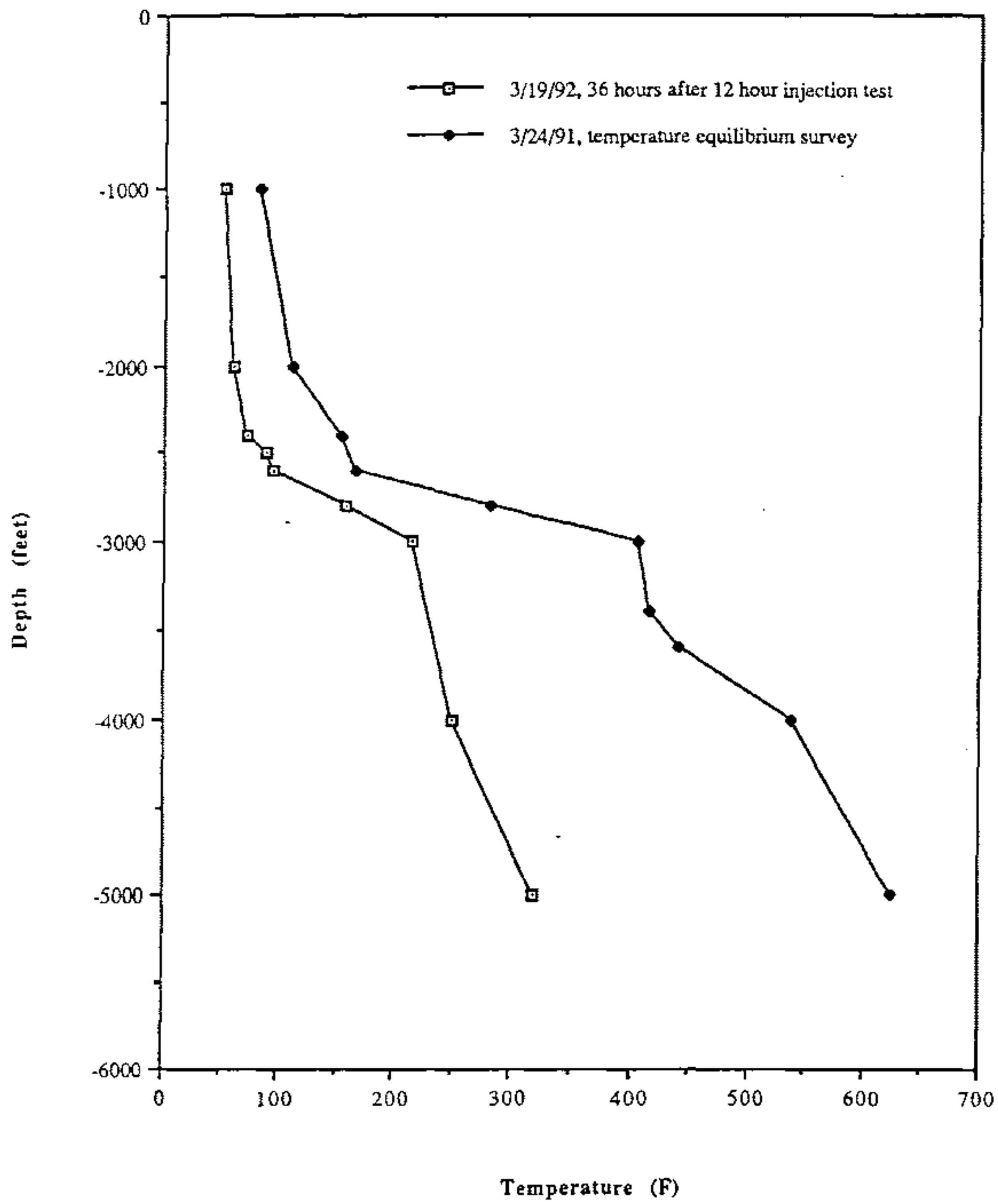


Figure 7. Static temperature surveys

4. Injection Capacity when Disposing of Power Plant Fluids

The injection capacity (Q) can be expressed as follows:

$$Q = II * [\ WHP + WD * \rho / 144 - SP - FP\ ]$$

where;

Q = injection flowrate (gpm)
II = injectivty index (gpm/psi)
WHP = wellhead pressure (psig)
WD = well depth to injection zone (ft)
ρ = density of injection fluid (lb/ft^3)
SP = static pressure at injection zone (psig)
FP = wellbore friction pressure drop of fluid being injected (psi)

The power plant injection fluids will be single phase liquid (noncondensible gases will be in solution at the injection pressure) at a temperature of 200°F. In the case of KS-3, the measured injectivity index (II) is 1.7 gpm/psi, the design injection wellhead pressure (WHP) is 150 psig, the well depth to the injection zone (WD) is assumed to be 5,000 feet, the injection fluid density (ρ) is 60.1 lb/ft^3 and the static pressure at the injection zone (SP) is 1779 psig. For the conditions relevant to this case the friction pressure drop can be expressed as follows;

$$FP = 0.91 * Q^2 / d^5$$

where d = effective internal diameter (inches)

For the existing 9 5/8" completion (effective internal diameter approximately 8.5"), the calculated injection capacity of KS-3 is 760 gpm. For a completion with a 7" liner hung from the surface to 3,750 feet (effective internal diameter 6.6") the injection capacity is 715 gpm.

It is likely that the injection capacity of KS-3 will increase with time under continuous long term injection as cool fluids migrate away from the wellbore and sink in the reservoir. As a result the injection capacities calculated here should be considered minimum values.

FILE COPY

March 16, 1990

Mr. Maurice A. Richard
Hawaii Regional Development Manager
Puna Geothermal Venture
101 Aupuni Street, Suite 1014-B
Hilo, Hawaii 96720

Dear Mr. Richard:

SUBJECT: PUNA GEOTHERMAL VENTURE PROJECT
UNDERGROUND INJECTION CONTROL (UIC)
UIC APPLICATION NO. UH-1529

This is to inform you that the Department of Health has completed its review of your preliminary application and has determined that the conditions for the granting of approval to construct up to three (3) dedicated injection wells and up to nine (9) production/injection wells at the subject facility have been satisfied. Therefore, you are hereby granted approval to construct the proposed injection wells as indicated in your preliminary plans. You are requested to notify the Safe Drinking Water Branch within 24 hours of the commencement and completion of construction activities. Unless construction is commenced within 180 days from the date of this letter, this approval to construct shall be terminated. Other applicable state and federal statutes and rules must also be complied with before construction may begin. Copies of this approval and the preliminary application must be kept on the construction site for inspection by department personnel.

Please be advised that this approval to construct does not constitute a permit to operate the injection facility upon completion of construction. The issuance of a UIC permit to operate will be based on the satisfactory review and acceptance of the following items:

1. A registered professional engineer or qualified geologist report (hereinafter "report") which includes the data and results of the injection tests.

2. A Hydrologic (groundwater) Monitoring Program (HMP).

3. A production well and injection well Casing Monitoring Program (CMP).

MAR 20 1990

The report as outlined in the application instructions under the heading "Construction of New Wells or Modification of Existing Wells" should be submitted following the construction and testing of the injection wells.

The department acknowledges the submittal of your hydrologic monitoring program (HMP) as prepared by Science Applications International Corporation. The HMP is currently being reviewed by the Safe Drinking Water Branch. Upon completion of the review, the department's comments will be submitted to you.

The department anticipates the submittal of your CMP as it will relate to the protection of the groundwater quality of the shallow aquifer. Your CMP will also be reviewed by the Division of Water and Land Development as it does relate to their regulations on geothermal activity.

If you have any questions regarding the processing of your application, please contact the Safe Drinking Water Branch at telephone 543-8258.

Sincerely,

James K Ikeda

JAMES K. IKEDA, Acting Chief
Environmental Management Division

CH:la

cc: 1) Rodney Nakano
Planning Commission
25 Aupuni Street
Hilo, Hawaii 96720

2) Dean Nakano
Division of Water and Land Development

UICCORR(PUNAGV01.OCH)

JOHN WAIHEE
GOVERNOR OF HAWAII

JOHN C. LEWIN, M.D.
DIRECTOR OF HEALTH

STATE OF HAWAII
DEPARTMENT OF HEALTH
P. O. BOX 3378
HONOLULU, HAWAII 96801

In reply, please refer to:
EPHSO

UNDERGROUND INJECTION CONTROL PROGRAM

The following is a simplified description of the Underground Injection Control (UIC) program.

1. **What:** The UIC program was created to protect underground sources of drinking water from contamination from injection well activity. Injection wells are wells that dispose fluids into the subsurface.

2. **When:** UIC rules have been in effect since July 1984.

3. **Why:** Over 90% of the State's drinking water comes from underground sources.

4. **How:** The protection of underground sources of drinking water is done by:
   a. evaluating injection well activities and
   b. regulating injection wells through a UIC permit.

5. **Where:** Statewide — all injection wells whether existing prior to July 1984 or made after July 1984 must have a UIC permit to operate.

6. **Contact person:** Chauncey Hew
   Geologist
   Safe Drinking Water Branch
   Environmental Management Division
   State Department of Health
   P. O. Box 3378
   Honolulu, Hawaii 96801-9984
   Telephone: 543-8258

Attached is a flow chart that describes the UIC application process leading to the issuance of a UIC permit. The highlighted boxes are the primary steps of the process. The following numbered items corresponds to the numbered highlighted boxes and provides a brief explanation.

1. A standard application form must be completed which generally describes the proposed injection well activity. A filing fee of $100.00 is required. The initial application is submitted before any construction occurs.

2. The UIC program staff reviews the initial application and determines if the application is satisfactory or if additional information is needed. The application (project) is assigned a file number.

3. A public notice of the proposed activity may be required dependent upon the project's location. A public hearing may result from the public notice dependent upon public response.

4. When all conditions of the initial application are met and are satisfactory, the Department issues a letter to the applicant granting an approval to construct and test the proposed injection well.

5. The applicant then constructs the injection well and performs required injection testing of the well.

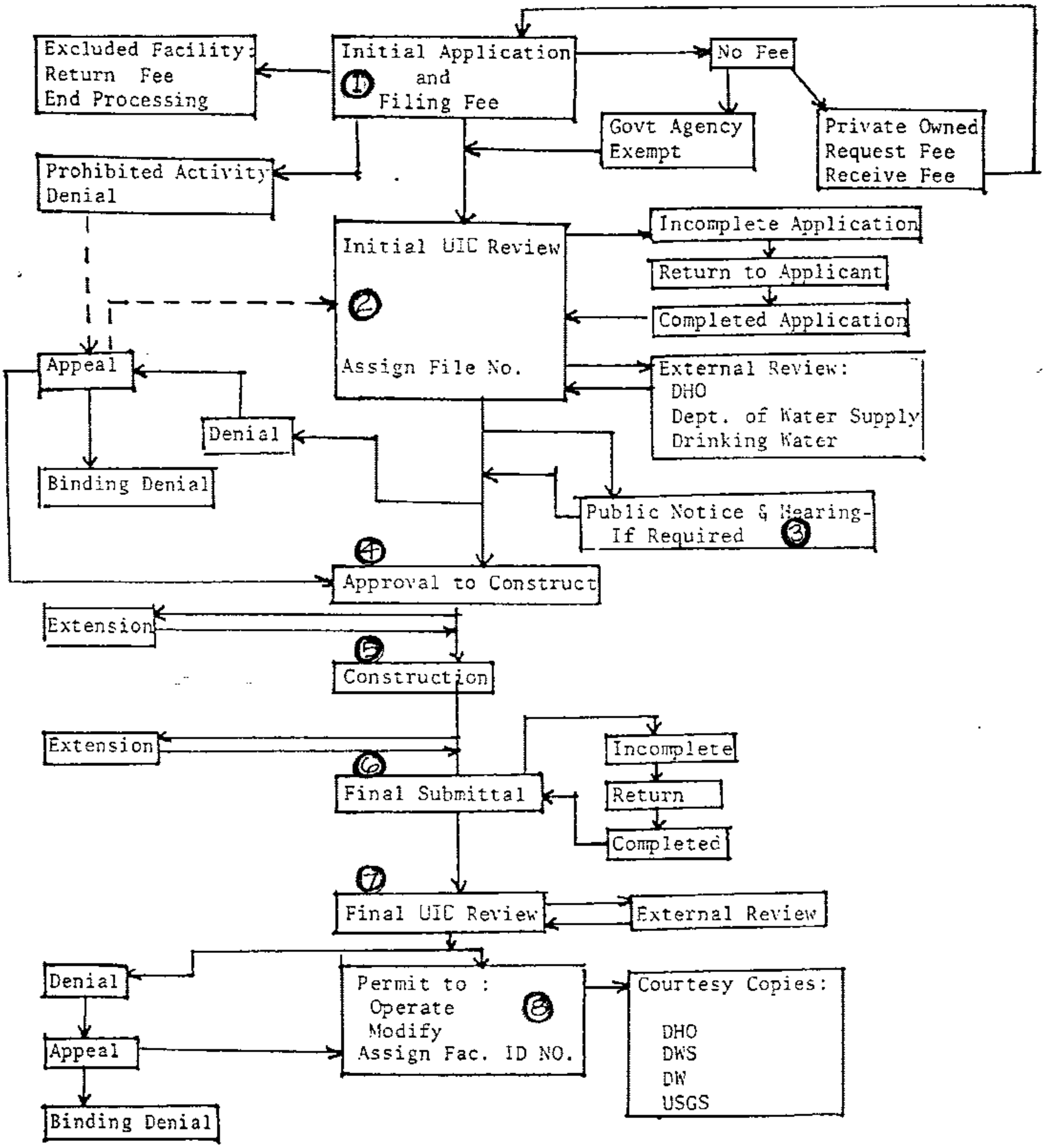
6. The "final submittal" or final application submittal consists of an engineer/geologist report summarizing the results of the construction and testing of the injection well. The format for this engineer/geologist report is specifically outlined in the initial application instructions.

7. The UIC program staff reviews the final submittal.

8. A UIC permit to operate is issued when all conditions in the final submittal are satisfactory. The permit is generally issued for a maximum duration of five years. The permit includes effluent monitoring requirements and general provisions. A unique identification number is assigned to the facility and the injection well.

If you have any quetions, please contact Chauncey Hew at the Safe Drinking Water Branch at 543-8258.

UIC PERMIT PROCESSING FLOW CHART
Proposed Well or Permit to Modify



TO ALL UIC APPLICANTS

Attached are supplemental instructions to assist you in completing your UIC application. These instructions are used in conjunction with:

a) Instruction sheet (first sheet with small print stapled with application)

and

b) Application Form

The items listed on this supplement correspond to the items on the application form.

Please remember, UIC permits for new injection wells involve a two-step application process. For example, if you plan to construct a new injection well you must:

1) Submit to the Department the information requested on the UIC application form (at least 180 days before the start of construction). This first application is called the Preliminary Application. The preliminary application is for obtaining an approval to construct the injection well.

2) After the injection well has been constructed and tested, you must submit a Final Application (including engineer/geologist report) which is used for obtaining an approval to operate and a permit.

SUPPLEMENTAL INSTRUCTIONS

1. Check "Individual Well" if applying for only one well.

   Check "Well System" if applying for more than one well. (Refer to 11-23-12 (c) if you want to read the regulations about Well Systems.)

2. Check appropriate box.

   State name of Drilling or Construction Company.

3. State full facility name or project name. This name will appear on all correspondence, official files and permit.

4a. Enter a street number and name. If no number available at the time, then give street boundaries and approximate dimensions of the subject parcel, and location of the parcel relative to street boundaries.

4b. Provide a map of the entire island with facility highlighted. A simple map will suffice, like the type in text books that show an entire island on one page, and can be xeroxed on an 8½" x 11" sheet.

4c. State Division, Zone, Section, Plat and Parcel numbers.

   Provide a copy of the TMK map showing TMK numbers and the exact location of the well(s) and well numbers. Highlight the wells.

4d. Provide a copy of the 1:24,000 scale USGS map. This is the 7½ minute quadrangle map. You do not need to give the entire quadrangle map, but give a portion large enough to identify the surrounding areas and surrounding pertinent features. Also plot on the map other wells (drinking water wells, injection wells, or other wells) within a ¼ mile radius of the facility. It's also recommended to plot the nearest drinking water well(s) even if they are more than ¼ mile away. Remember, one of the primary concerns of UIC are the locations of drinking water wells in proximity to your injection well.

   Where do you find these maps with well locations? The maps with these drinking water wells on them can be found at:

a) SAFE DRINKING WATER BRANCH	State agency with office on Oahu only.
b) Department of Land & Natural Resources (DLNR)	State agency with outer island District offices.
c) Department of Water Supply	County agency.
d) USGS	Federal agency.

For Oahu applicants, all the sources listed above are available.

For other island Applicants, sources b) and c) would be your best and most convenient choices. Check with both sources because one may have some information the other one does not have.

Once you find these maps of the different wells you should try to keep a copy for your library and future reference.

4e: State latitude and longitude of the well(s) as plotted on your 7½ minute quadrangle map. If there is a system of wells, state a latitude and longitude of a representative point which is central.to all of the wells.

Note: If your parcel is small, the coordinates of your parcel's central point compared to the coordinates of your well on the parcel will be nearly the same when determined from the 7½ minute quadrangle map.

Remember that if your wells are spread apart, like on several different parcels, you may have to apply for individual permits instead of a well system permit.

List coordinates down to, at least, the nearest 2 seconds. Remember, every second changes your map distance by about 95 feet in longitude, 100 feet in latitude.

5. State the name of the person(s), company, or corporation, etc. that will own the injection well. If property is leasehold, give a copy of the lease agreement (the "meat" of the agreement) and a written consent from the fee owner stating that he approves of this activity and UIC application.

6. Enter the name, position, address and telephone number of the owner or legal contact of Item 5. All UIC correspondence will be made through this person.

   Note: This is not the name of the engineer that is processing the application, nor is it the name of the architect for the project. The engineer who is processing the application will be given courtesy copies of the correspondence.

7. Check the appropriate box.

8. Enter your design discharge into the well.

   For drywells, give an approximate volume of runoff, per time, the drywell should be able to handle based on rainfall intensity and the amount of excess runoff generated because of the development on your parcel.

9. Enter your proposed injection rate and pressure. Generally, this rate should be equal to or greater than the rate given in Item 8. If you have a well system, then give the rate for the entire system.

   Usually for drywells the injection rate is "variable" and the pressure is "gravity".

10. Also state, with the system description, the total number of injection wells.

11. Describe the injection testing you will be doing on your well(s) once the well is made. The data obtained from this testing will enable your engineer and geologist to evaluate the performance of your well and complete the engineer/geologist report.

Remember again, the application for a UIC permit is a two-step process for wells to be made. The preliminary application, which you are filling out now, will ultimately give you approval to construct your well(s) after our review and approval of your preliminary application. You are then required to injection test your well(s). After this testing, you submit the final application along with the engineer/geologist report to us for final review to ultimately obtain approval to operate. Approval to operate comes with your permit.

12. Provide data from nearest supply wells. If there are no data for individual supply wells or there are no nearby supply wells, then give data from the water supply system that serves the area of your facility. You can get this information from:

SAFE DRINKING WATER BRANCH

a) ~~Drinking Water Program~~ (office on Oahu only) at ~~645 Halekauwila St.~~, Honolulu, Hawaii 96813 5 WATERFRONT #250 500 ALA MOANA BLVD. HON. HI. 96813

b) District Health Office (for outer islands)

c) Department of Water Supply (on all islands)

Note: to get information from these various agencies, a person may be required to fill out a Request for Public Record form. Call agency to find out what is required.

Keep an original copy for your files. The data is updated periodically, but if subsequent applications are made for different projects in the same areas, you still can use this data to submit with your new applications. Always submit the latest data available.

13a. This deals with a situation where the UIC line coincides with an existing roadway. If your wells and property are next to the UIC line (roadway), or when the UIC line runs through your property and is situated near your wells, you will need our interpretation of your well siting to see if you are in an exempt or non-exempt aquifer area.

13b. Generally, in areas where caprock or other sedimentary materials overlie volcanic aquifers, artesian conditions may exist. Hydrogeologic conditions must be researched for your project site. Geologic books or maps covering your area can provide information. Also, the Department of Water Supply can provide you with information concerning the aquifer underlying your site.

14. This is essentially a sketch of your proposed well or existing well. You can make your own sketch of the cross section of your well, for clarity's sake, but be sure to provide all applicable information on the sketch.

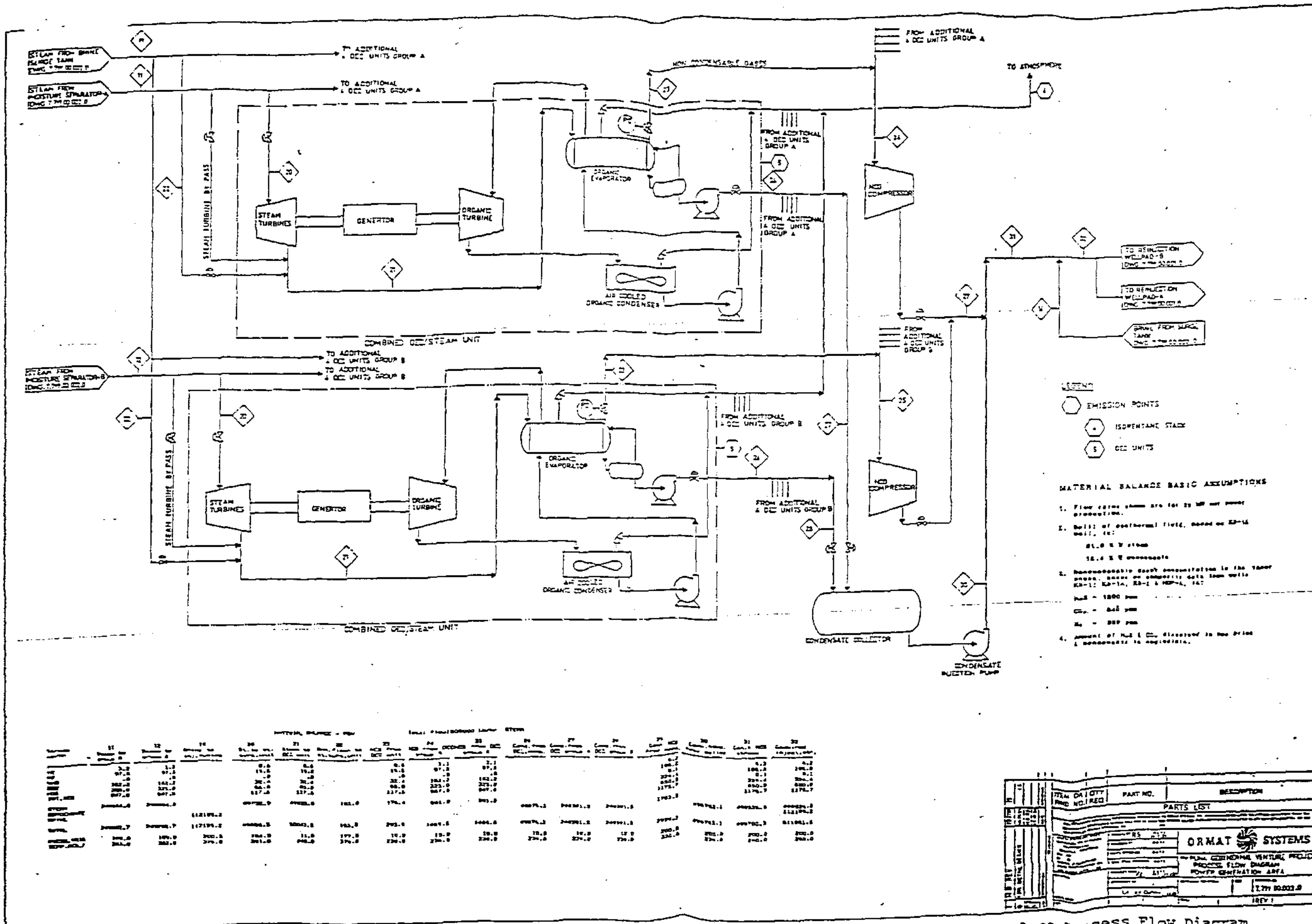
Note: If you have to submit information for a number of wells, you can use a table format for convenience, for example:

	Depth	Diameter	Grd.Elev.	Bottom Elev.	Proposed Discharge	....Etc.
Well #A						
Well #B						
Well #C						
.						
.						
.						

15. Signatory and Certification Statement: The owner or legal contact of the injection well must sign and date. This will be the person listed in item 5) or 6); whichever is applicable.

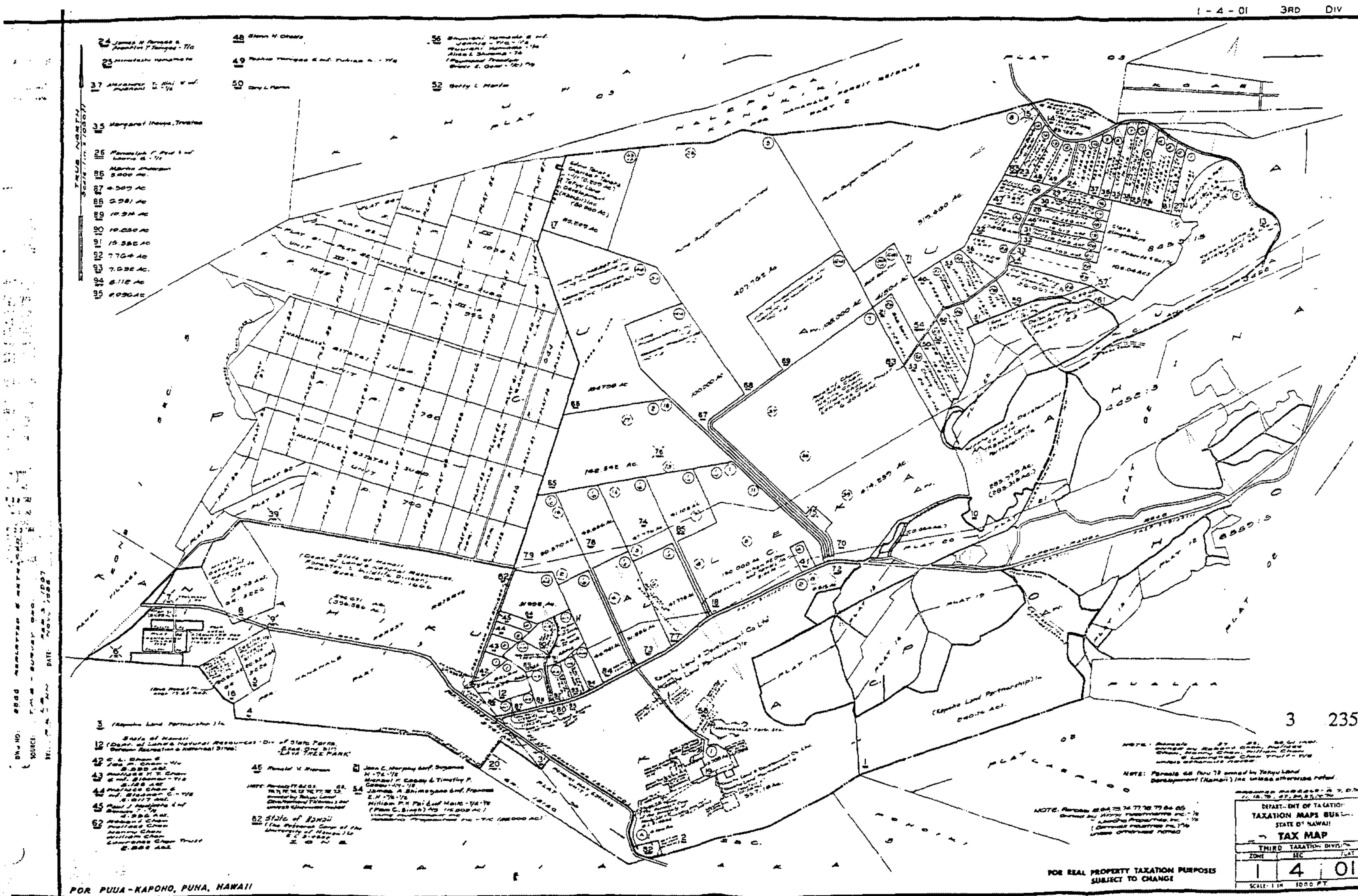
CH:la
5/10/88

FIGURE 5



Power Generation Area Process Flow Diagram
(Dwg. No. 7.799.00.003.0)

FIGURE 1


1 - 4 - 01 3RD DIV
TRUE NORTH
POR. PUUA - KAPOHO, PUNA, HAWAII
FOR REAL PROPERTY TAXATION PURPOSES SUBJECT TO CHANGE
3 235
DEPARTMENT OF TAXATION
TAXATION MAPS BUREAU
STATE OF HAWAII
TAX MAP
THIRD TAXATION DIVISION
ZONE SEC. PLAT
1 4 01
SCALE: 1 IN = 1000 FT.